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13. ABSTRACT (Maximum 200 words)
THE OBJECT OF THIS REPORT WAS TO DEVELOP, ANALYZE AND EVALUATE VARIOUS SURFACE TREATMENT ALTERNATIVES TO STABILIZE THE SURFACE OF BASIN A AT RMA AND TO STOP POTENTIAL WINDBLOWN CONTAMINATION AND/OR LEACHING OF CONTAMINATION INTO GROUNDWATER. IN ORDER TO IDENTIFY WHAT TECHNIQUES MIGHT BE AVAILABLE AND APPLICABLE, RESEARCHERS FORMULATED A FOUR PART APPROACH: LITERATURE SEARCH, LITERATURE SELECTION PROCESS, LITERATURE REVIEW PROCESS AND THE SELECTION OF POTENTIAL TECHNIQUES.

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Report

ROCKY MOUNTAIN ARSENAL
BASIN A
SURFACE STABLIZATION ALTERNATIVES

CONTRACT NO. DAAG-29-76-D-0100
DELIVERY ORDER 1523

to

U.S. Army
Toxic and Hazardous Materials Agency
Aberdeen Proving Ground
Maryland, 21010

DISCLAIMER

The views, opinions, and/or findings contained in this report are the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

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PART I. INTRODUCTION AND BACKGROUND

INTRODUCTION

For many years, industrial and municipal waste has been disposed of by dumping on the surface of the land. In recent years it has become increasingly apparent that this disposal practice has resulted in numerous incidents of soil, surface water, and groundwater contamination. This pollution has come under increasing public scrutiny and is resulting in new regulatory controls on waste disposal practices. Procedures that were once acceptable are not any longer and pollution resulting from past disposal operations must, in many instances, be cleaned up. The Department of Defense, recognizing that pollutants could be migrating from sites used in the past for disposal of wastes generated during the manufacture of military materiel, established a program of Installation Restoration (IR) under the Department of the Army. This program was designed to survey potential problem sites, quantify pollution problems and institute remedial measures when necessary. The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) at Aberdeen Proving Ground, Maryland, is directing the IR program.

Rocky Mountain Arsenal (RMA) was one of the first sites identified under the IR program as having potential problems. Subsequent investigations have established that the soil and groundwater beneath portions of RMA are contaminated with toxic industrial wastes. The largest source of contamination was identified as Basin A, a large shallow depression formerly used for disposal of industrial waste.

Battelle Columbus Laboratories (BCL) was awarded Delivery Order 1523 on contract DAAG-29-76-D-0100. The objective of the delivery order was to develop, analyze and evaluate various surface treatment alternatives to stabilize the surface of Basin A at RMA to stop potential windblown contamination and/or the leaching of contamination into groundwater. As part of the contract, accomplishment of the following tasks was specified:

(1) Attend a task initiation meeting at THAMA Headquarters, Aberdeen Proving Ground, MD.

(2) Conduct a review of reports, provided by USATHAMA to obtain necessary background information.

(3) Visit RMA to inspect the topography, and talk to appropriate personnel to obtain necessary and available data.

(4) Obtain and analyze available data on precipitation and evaporation rates. Obtain an understanding of surface water flow conditions in Basin A. Estimate surface water flow rates, and infiltration and evaporation rates.

(5) Investigate (Literature Search), list, and summarize various surface stabilization techniques.

(6) Examine in accordance with the objective the most promising (minimum of 2) stabilizing techniques when considering cost, technical feasibility, and schedule. This examination must include the most promising approaches for dealing with the wind-blown dust problem on a short term basis, with a long term goal of eliminating (minimizing) the leaching problem and maintaining dust control. The short term goal must be quickly effective, easy to implement, and should not hinder the long term effort. A minimum of two techniques will be considered for each of the objectives, the short and long term.

Work on this contract was initiated with a trip to USATHAMA Headquarters by Battelle staff in late April 1980. Following the task initiation meeting, Battelle was provided with a number of documents for review. These publications (see Appendix A) provided background information on RMA, hydrogeologic data, the nature and extent of contamination, and a listing of chemicals found in the soils and groundwater at Basin A.

During early May, Battelle researchers were conducted on an inspection tour of RMA with emphasis on Basin A. During the visit, Dr. William Troutmann and Brian Anderson (Contamination Migration Branch, Ecological Division, RMA), Don Marlow (Director of Facilities, Buildings, Grounds and Facilities, RMA), and Sgt. First Class Glen Goodman (Meteorological Detachment, assigned temporary duty to RMA) were interviewed. These interviews provided much additional insight into past operations and events at RMA Basin A.

BACKGROUND

Rocky Mountain Arsenal is located in Adams County, Colorado, 10 miles northeast of the geographic center of Denver. The arsenal occupies 17,000 acres immediately north of Denver's Stapleton International Airport (Figure I). The arsenal was established in 1942 for the manufacture and assembly of military chemical material. Since 1946, certain portions of the arsenal were leased to private industry for chemical manufacturing. Shell Chemical Company has held the lease since 1952 and has been engaged in the manufacture of various pesticides. During the period 1953 to 1957, nerve agent GB was produced at the arsenal. From 1972 to present, the arsenal has been used for the demilitarization of obsolete mustard stocks and GB nerve agent (Shell maintains its lease).

From 1942 to 1956 all contaminated or industrial waste from government and lessees plants were discharged into Basin A north of the Plant's area (see Figure II). After the GB production complex was completed, Basin A was enlarged and Basins B, C, D, and E were added.

In 1951, minor crop damage was reported on a farm irrigated by groundwater northwest of RMA. During the summer of 1954 several farmers complained that groundwater used for irrigation had damaged their crops. As a result of these complaints, and subsequent investigations, construction of an asphalt lined lagoon (Basin F) was initiated in 1956. Upon completion of Basin F in 1957, the use of Basins A, B, C, D and E were discontinued and the basins were allowed to drain. From 1957 to 1978 all industrial discharges went to Basin F.

During 1974, diisopropylmethylphosphonate (DIMP) was detected in surface water draining from a bog on the northern boundary of the arsenal, and in a well near the City of Brighton. Although the concentrations were very low, this indicated that groundwater traveled in a northerly direction (later studies have confirmed this).

Upon confirmation that contaminants had migrated off the northern boundary of RMA, the Secretary of the Army tasked the Project Manager for Chemical Demilitarization and Installation, now the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), with the RMA restoration program.

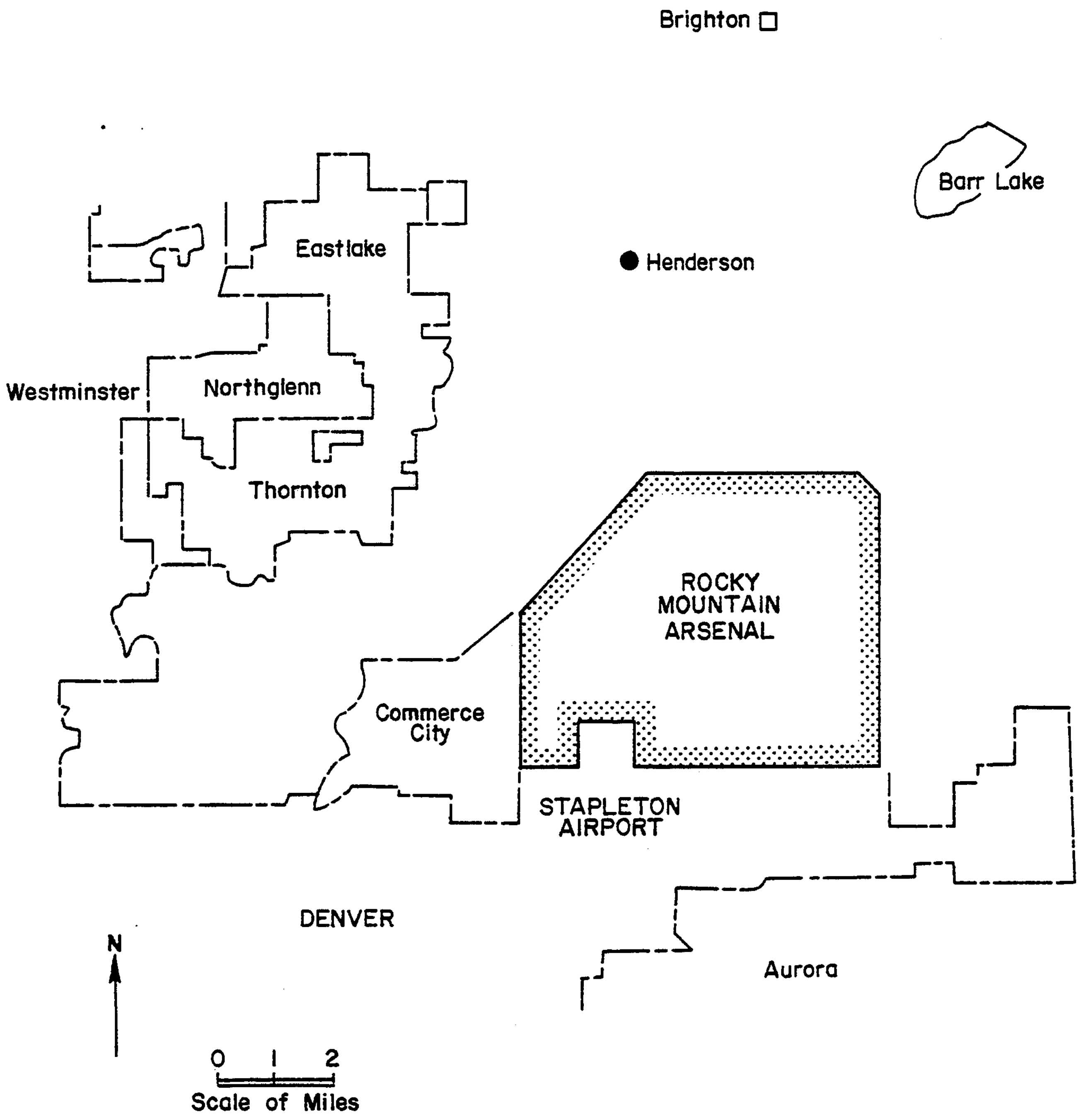

FIGURE I. ROCKY MOUNTAIN ARSENAL AND VICINITY

Source: USATHAMA, Map attached to Delivery Order.

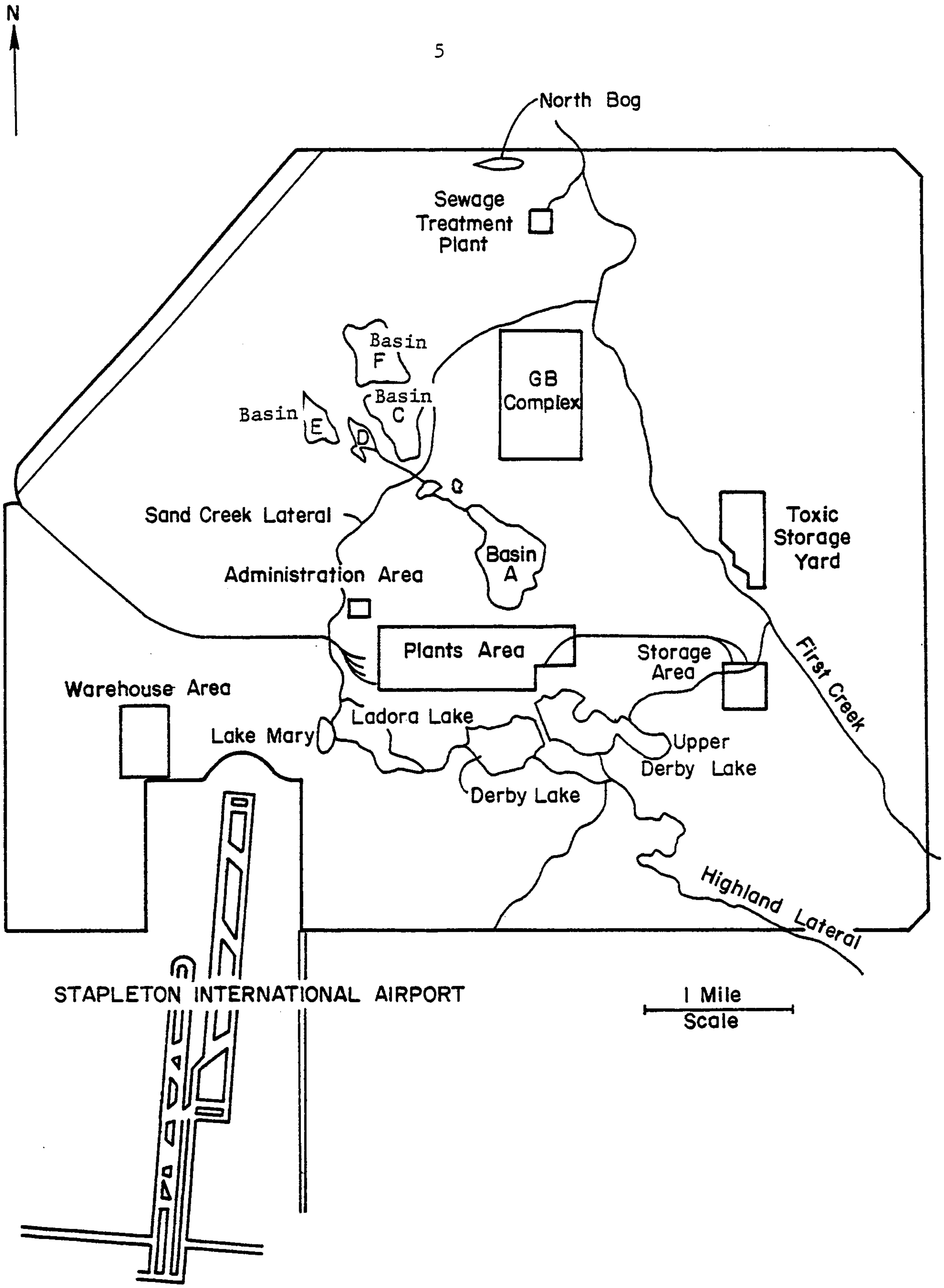

FIGURE II. GENERAL MAP OF ROCKY MOUNTAIN ARSENAL

Source: Basin A Groundwater Quality Analysis Draft Report, by Joseph Kolmer U.S. Army Engineer Waterways Experiment Station, July 1979.

PART II. GENERAL TECHNIQUE SELECTION

In order to identify what techniques might be available and applicable to the stabilization of soils at RMA, Basin A, BCL researchers formulated a four part approach: a literature search, literature selection process, a literature review process, and the selection of potential techniques.

LITERATURE SEARCH

A computer aided literature search was initiated, utilizing the resources of the Battelle library system. The search was initiated by formulating the following list of key works:

Basin	Earth	Leach	Reservoir
Cement	Erosion	Liner	Soil
Control	Lagoon	Pond	Stabilize
Dirt	Landfill	Prevent	Surface

These words and variations of them were combined in various forms and processed through the computer programs of four indexing and abstracting services, Chemical Abstracts, Agricola, Engineering Index, and Commonwealth Agricultural Bureaus Abstracts, all of which are found in the Lockheed Information Retrieval System (DIALOG). Lists of references that resulted from selected word combinations were printed out. The source, range of years, and the number of references that were printed out are shown in Table 1. A total of 1461 references were producted by the literature search, which spanned the years 1970-1980. Many of the references were received with brief abstracts which were used extensively in the literature selection process.

TABLE 1. LITERATURE SEARCH NUMERICAL RESULTS

Source	Year	Number of References
Engineering Index	1970-80	301
Agricola	1970-80	509
Chemical Abstracts	1967-80	339
Commonwealth Agricultural Bureaus	1972-80	312
		1461

LITERATURE SELECTION PROCESS

The literature selection process consisted of a dual screen of all the references. A BCL hydrogeologist and a civil engineer evaluated the titles and abstracts of the references and determined which ones contained potentially useful information for resolving the problems at Basin A. The Battelle library resources were then utilized again to locate and acquire the selected references. This process entailed borrowing publications through interlibrary loan, ordering documents from the National Technical Information Service, and obtaining materials from in-house sources. This resulted in the accumulation of 49 references which were then reviewed.

LITERATURE REVIEW PROCESS

The review process consisted of reading the collected materials and evaluating the techniques presented therein. These techniques covered two broad categories: (1) soil stabilization/erosion minimization and (2) minimizing infiltration. The primary intent in reviewing techniques in the first category was to find effective methods of controlling wind erosion on both a temporary and a permanent basis. These methods are generally derived from agricultural-and construction-related attempts to control wind erosion of

soils and dust. The second category concerns the long range objective of minimizing the infiltration of liquids into the soil and into underlying aquifers. These techniques have been developed out of a need to prevent contamination of aquifers by a variety of chemical materials and from a need to minimize seepage from surface water reservoirs used for irrigation, drinking water, and other public and commercial uses.

The 49 articles and reports were then abstracted, with emphasis on the two categories described above. Appendix B lists the articles and abstracts.

POTENTIAL TECHNIQUE SELECTION

From the review and evaluation of the currently available techniques potentially applicable to the contamination problem at Basin A, two basic concepts of accomplishing the project objectives became apparent. The first was to cover the soil surface; the second was to incorporate a substance into the soil. A variety of materials and techniques were indentified which could potentially be used to accomplish the objectives of the Basin A stabilization project.

Table 2 shows all of the techniques potentially applicable to the project categorized under the basic concepts as gleaned from the technique selection process.

TABLE 2. TECHNIQUES TO PREVENT WIND EROSION AND LEACHING OF CONTAMINANTS INTO GROUNDWATER

Cover Materials		Incorporation of Chemical Cements	
Natural	Artificial	Inorganic Chemicals	Organic Chemicals
Uncontaminated clay soils	Concrete	Silicates	Oils
Crushed rock	Asphalt	Chlorides	Asphalt
Gravel	Plastic Sheeting	Sulfates	Polymers
Bentonite clays	Rubber Sheeting	Water	Emulsions
Mulches			Resins
Vegetation			

The next three sections of this report discuss the further refinement and evaluation of these potential problem solving techniques.

PART III. PROGRESS REVIEW, APPROACH FORMULATION

On June 6, 1980, Battelle's Columbus Laboratories researchers attended a progress review meeting at USATHAMA Headquarters. Battelle presented a written and oral report on the current status of the project, including a discussion of the potential surface stabilization techniques gleaned from the literature search. Battelle proposed a dual process that could be utilized to screen out nonapplicable or undesirable surface stabilization techniques. The concept was to reduce the number of potential techniques so that the best ones could be studied in depth.

The first screen would be entiled a preliminary or general screen and was designed to eliminate techniques that would not work, those in which regulatory or permit problems were anticipated, or those that would conflict with other USATHAMA goals at RMA.

The second screen was to be technical and designed to evaluate the technical merits and demerits of each technique.

It was concluded that this was the best approach and that the dual screening process would result in a "ranking" of the techniques. Another meeting was scheduled for June 20 to review the results of the screening process and to select the most promising techniques for detailed analysis.

PART IV. PRELIMINARY (GENERAL) SCREEN OF TECHNIQUES

In order to perform the preliminary screening of techniques, a list of questions was compiled. The questions and techniques were then organized on four forms (Tables 3, 4, 5, 6) with the headings: Cover Materials - Natural, Cover Materials - Artificial, Chemical Cements - Inorganic, Chemical Cements - Organic. The forms were designed so that each question addressed the short term and long term objectives separately.

A panel of BCL research scientists with expertise in hazardous waste (Dr. Gary L. McKown), Government regulations and permit requirements (Richard P. Moffa), geology (David E. Johe), water quality (Terry A. Bowen), and engineering (David A. Sharp) was convened to perform the screening process.

TABLE 3. COVER MATERIALS - NATURAL

	Local, Clean Clay Soil	Crushed Rock	Gravel	Bentonite Clay	Mulch	Vegetation
1. Does technique meet objectives?						
Short Term	Yes	Yes	Yes	Yes	Yes	No
Long Term	?*	No	No	?	No	Yes
2. Is technology sufficiently developed?						
Short Term	Yes	Yes	Yes	Yes		
Long Term	Yes			Yes		Yes
3. Is technique technically feasible (size, scale, control)?						
Short Term	Yes	Yes	Yes	Yes		
Long Term	Yes			Yes		Yes
4. Does technique meet regulatory requirements?						
Short Term	Yes	Yes	Yes	Yes		
Long Term	Yes			Yes		Yes
5. Major permit problems anticipated?						
Short Term	No	No	No	No		
Long Term	No			No		No
6. Is time frame for application/operation acceptable?						
Short Term	Yes	Yes	Yes	Yes		
Long Term	Yes			Yes		Yes
7. Does technique interfere for RMA?						
Short Term	No	No	No	No		
Long Term	No			No		No

* Signifies conditional.

TABLE 4. COVER MATERIALS - ARTIFICIAL

	Concrete	Asphalt	Plastic Sheeting	Rubber Sheeting	
1. Does technique meet objectives?					
Short Term	Yes	Yes	Yes	Yes	
Long Term	?*	?	?	?	
2. Is technology sufficiently developed?					
Short Term	Yes	Yes	Yes	Yes	
Long Term	Yes	Yes	Yes	Yes	
3. Is technique technically feasible (size, scale, control)?					
Short Term	Yes	Yes	Yes	Yes	
Long Term	Yes	Yes	Yes	Yes	
4. Does technique meet regulatory requirements?					
Short Term	Yes	Yes	Yes	Yes	
Long Term	Yes	Yes	Yes	Yes	
5. Major permit problems anticipated?					
Short Term	No	No	No	No	
Long Term	No	No	No	No	
6. Is time frame for application/operation acceptable?					
Short Term	Yes	Yes	Yes	Yes	
Long Term	Yes	Yes	Yes	Yes	
7. Does technique interfere for RMA?					
Short Term	No	No	No	No	
Long Term	No	No	No	No	

* Signifies conditional.

TABLE 5. CHEMICAL CEMENTS - INORGANIC

	Silicates	Chlorides	Sulfates	Water	
1. Does technique meet objectives?					
Short Term	Yes	No	No	Yes	
Long Term	Yes	No	No	No	
2. Is technology sufficiently developed?					
Short Term	Yes			Yes	
Long Term	?*				
3. Is technique technically feasible (size, scale, control)?					
Short Term	Yes			Yes	
Long Term	Yes				
4. Does technique meet regulatory requirements?					
Short Term	Yes			Yes	
Long Term	Yes				
5. Major permit problems anticipated?					
Short Term	No			No	
Long Term	No				
6. Is time frame for application/operation acceptable?					
Short Term	Yes			Yes	
Long Term	Yes				
7. Does technique interfere for RMA?					
Short Term	No			No	
Long Term	No				

* Signifies conditional.

TABLE 6. CHEMICAL CEMENTS - ORGANIC

	Oils	Asphalt	Polymers	Emulsions	Resins	
1. Does technique meet objectives?						
Short Term	Yes	Yes	Yes	Yes	Yes	
Long Term	No	?*	Yes	No	Yes	
2. Is technology sufficiently developed?						
Short Term	Yes	Yes	No	Yes	No	
Long Term		Yes	?		?	
3. Is technique technically feasible (size, scale, control)?						
Short Term	Yes	Yes		Yes		
Long Term		Yes	Yes		Yes	
4. Does technique meet regulatory requirements?						
Short Term	No	Yes		No		
Long Term		Yes	Yes		Yes	
5. Major permit problems anticipated?						
Short Term		No				
Long Term		No	No		No	
6. Is time frame for application/operation acceptable?						
Short Term		Yes				
Long Term		Yes	Yes		Yes	
7. Does technique interfere for RMA?						
Short Term		No				
Long Term		No	No		No	

* Signifies conditional

Each of the short term techniques was addressed separately, question by question, followed in the same manner by the long term techniques. Results of the screening process are summarized in Tables 3 through 6.

The following techniques were rejected as a result of the preliminary screening process:

(1) Vegetation was eliminated as a short term solution because the background data supplied by USATHAMA established that vegetation will not grow on the contaminated soils in Basin A.

(2) Oils and emulsions were eliminated due to anticipated regulatory and permit problems. It was also agreed that the application of these would add to the long term problems - would contribute additional organic contaminants to the groundwater.

(3) Polymers and resins were eliminated as a short term technique because not enough is known about the long range effects. The concept of using various polymers and resins is relatively new and the panel felt that not enough is known about their use to receive an unconditional endorsement.

(4) and (5) Chlorides and sulfates were eliminated as a short term solution because their use for dust control relates to their hygroscopic nature - they attract moisture from the air to keep the soil surface damp. This will not work in the dry (low humidity) conditions at RMA.

Chlorides and sulfates were also eliminated as a long term solution because they are highly soluble in water and would add to the groundwater contamination problem.

The techniques that were not eliminated as potential short term solutions are listed in Table 7, the long term techniques are listed in Table 8. During the screening of the long term potential techniques it became readily apparent that none of the techniques could be used unconditionally. All techniques required regular maintenance or could be used only in combination with other listed techniques. In addition, the idea of constructing a large building or buildings over the basin was added to the list of options to be considered.

TABLE 7. CONCEPTS FOR TECHNICAL SCREENING
SHORT TERM OBJECTIVE

A) COVER

1) LOCAL CLAY SOIL
2) CRUSHED ROCK, GRAVEL
3) MULCH
4) BENTONITE CLAY
5) CONCRETE
6) ASPHALT
7) PLASTIC SHEETING , RUBBER SHEETING

B) SOIL CEMENTS

1) SILICATES
2) WATER
3) ASPHALT
4) PORTLAND CEMENT

TABLE 8. CONCEPTS FOR TECHNICAL SCREENING
LONG TERM OBJECTIVES

A) COVER

1) LOCAL CLAY SOIL
2) BENTONITE CLAY
3) VEGETATION
4) CONCRETE
5) ASPHALT
6) PLASTIC AND RUBBER SHEETING

B) SOIL CEMENTS

1) SILICATES
2) ASPHALT
3) POLYMERS AND RESINS
4) PORTLAND CEMENT

C) CONSTRUCT LARGE BUILDING OR BUILDINGS

PART V. TECHNICAL SCREEN OF TECHNIQUES

SCREENING APPROACH

The approach utilized for the technical screening process was similar to that utilized in the preliminary screening process. A list of 17 questions was compiled (Table 9) and the techniques were listed by Short Term Objective (Table 7) and Long Term Objective (Table 8).

All techniques were addressed by a panel of BCL members with expertise in geology (David E. Johe), engineering (David A. Sharp), agronomy and soils (Dr. Lee Taft), and water quality (Terry Bowen). All of the questions (Table 9) were addressed toward each of the short term techniques followed, in turn, by the long term techniques.

Highlights of the technical screening session are shown in Tables 10, 11, 12, and 13. These tables, entitled Technical Screening Session Highlights: Short Term Objective(s)--Cover (Table 10), Short Term Objective(s) Soil Cements (Table 11), Long Term Objective(s)--Cover (Table 12), and Long Term Objective(s)--Soil Cements (Table 13), list the techniques vertically and the highlights horizontally. The highlights selected address the questions: (1) Will the technique work by itself? (2) Will it work conditionally? (3) In addition to accomplishing the objectives, are there any additional benefits to be derived from the use of the technique? (4) What are the deficiencies of the technique? and (5) What conditions are placed upon the technique?

RESULTS OF SHORT TERM OBJECTIVE SCREENING

A review of the data readily showed that all of the short term objective techniques, with the exception of bentonite clay and portland cement, will work by themselves. However, many of the techniques have deficiencies or limitations and others have additional benefits. BCL was able to rank the short term objective techniques by considering the positive and negative aspects of each technique. Table 14 shows the short term techniques ranked under the subheadings: Serious Limitations, Some Limitations, and Few Limitations.

TABLE 9. ROCKY MOUNTAIN ARSENAL - BASIN A
TECHNICAL SCREENING CRITERIA

(1) Will the concept prevent windblown contamination at RMA?

Short Term?

Long Term?

(2) Will the concept eliminate or minimize infiltration of contaminants into groundwater?

(3) Is the technique well established?

(4) Based upon case histories, what is the "track record" of the concept? Are there unknowns?

(5) What is the anticipated "life" of the technique in Basin A?

(6) What effect will the following have on the technique:

a) Sunlight	d) Humidity
b) Heat	e) Precipitation
c) Cold	f) Wind

(7) Is the integrity of the technique subject to failure due to chemical reactions?

Physical damage?

(8) Can damage to the integrity of the technique be prevented? or minimized?

(9) Can the proper quality control during installation of the concept be written into a contract ?

(10) Can quality control be quaranteed during actual installation? How difficult a task would this be? Need experts or specialized equipment to perform Q.C.?

(11) Are there any unknown factors to be considered during installation?

TABLE 9. Continued

(12) Are there any known hazards to the subcontractor during installation? Anticipate any unforeseen hazards?

(13) Can performance of the technique be evaluated/monitored?

(14) Is periodic maintenance required? Need skilled people? Specialized equipment?

(15) Can "failures" to the technique be located and repaired? Need skilled people? Specialized equipment?

(16) Could use of the technique to accomplish Basin A goals have detrimental side effects (e.g., could increased runoff cause problems somewhere else)?

(17) Could the materials used produce any hazardous side effects by chemical reaction?

18) Are there any additional benefits as a result of the technique?

TABLE 10. TECHNICAL SCREENING SESSION HIGHLIGHTS: SHORT TERM OBJECTIVE(S) - COVER

Concept	Will it work by itself?	Will it work conditionally?	Hazards	Additional Benefits	Deficiencies	Conditions
Local Clay Soil	yes		yes	Part of long term		
Crushed Rock, Gravel	yes		yes	Part of long term		
Mulch	yes		yes	None	Could catch fire Blow away Wash away	Depth of mulch needed? Continual maintenance.
Bentonite	no	yes	yes	None	Cracks do not reseal upon wetting.	Thickness needed. Must be kept wet.
Concrete	yes		yes	Parking, outdoor storage. Part of long term	Greatly increased runoff	
Asphalt	yes		yes	Parking, outdoor storage Part of long term	Greatly increased runoff	
Plastic and Rubber Sheeting	yes		yes	None	Could blow away. Punctures easily. Difficult to maintain. Q.C. during install. cannot be guaran. Continual maintenance. Increased runoff. Chemical reaction unknown. What liner material to use?	Must be anchored (covered). Guarantee no sharp objects above, below to puncture.

TABLE 11. TECHNICAL SCREENING SESSION HIGHLIGHTS: SHORT TERM OBJECTIVES(S) - SOIL CEMENTS

Concept	Will it work by itself?	Will it work Conditionally	Hazards	Benefits	Deficiencies	Conditions
Silicates	Yes		Yes	None	Weather deteriorates (freeze-thaw).	Rate of application-penetration needed is unknown.
Water	Yes		Yes	None	Increases infiltration problem.	Must keep soil moist.
Asphalt	Yes		Yes	None	Weather deteriorates. Chemical reaction (dissolve). Increased runoff.	Cannot be in contact with organic waste.
Portland Cement	No	No	Yes	Increased bearing strength	Not effective for dust control.	

TABLE 12. TECHNICAL SCREENING SESSION HIGHLIGHTS:
LONG TERM OBJECTIVE(S) - COVER

Concept	Will it work by itself?	Will it work conditionally?	Hazards	Benefits	Deficiencies	Conditions
Local Clay Soil	NO	Yes	Yes	Wildlife Habitat. Aesthetics	Subject to erosion. Must have barrier to eliminate capillary movement of contaminants, keep plant roots from penetrating barrier.	Need erosion control (vegetation). Need barrier Minimize prairie dog problems.
Bentonite Clay	No	Yes	Yes	None	Must be kept moist (covered). Subject to destruction by ion exchange (dispersion by Cl). Support local vegetation? Q.C. during installation difficult. Failures cannot be located. Plus those listed for local clay soil	Cover or apply sufficient thickness. Eliminate contact with contaminants.
Concrete	No	Yes	Yes	Parking lot Runway Building floor Outdoor storage	Annual maintenance weed control cracks, joints. 50 year life aesthetics. Do not allow contact with waste (Cl). Increased runoff.	Requires subgrading, subdrainage. Continuous repair. Eliminate plant growth.

TABLE 12. (CONTINUED)

LONG TERM OBJECTIVE(S) - COVER

Concept	Will it work by itself?	Will it work conditionally?	Hazards	Benefits	Deficiencies	Conditions
Asphalt	No	Yes	Yes	Building floor Parking lot Outdoor storage	Expected life 20+ years with dressing. Maintenance Increased runoff.	Requires sub-grading, sub drainage, Continual repair. Must be "dressed" every 5 years. Eliminate plant growth.
Plastic and Rubber Sheeting	No	Yes	Yes	None	Must be covered. No guarantee - life time unknown. Reaction with contaminants unknown. Cannot locate "failures". Highly vulnerable to physical damage. Q.C. done statistically, cannot be guaranteed.	Must cover for protection from sun, wind. Must not have any sharp objects in subsoil or cover.

TABLE 13. TECHNICAL SCREENING SESSION HIGHLIGHTS: LONG TERM OBJECTIVE(S) - SOIL CEMENTS

Concept	Will it work by itself?	Will it work conditionally?	Hazards	Benefits	Deficiencies	Conditions
Silicates	No	No	Yes	None	Not viable technique for dust control (long term). Does not eliminate infiltration.	
Asphalt (Bituminous)	No	Yes	Yes	None	1 year life. Sun deteriorates asphalt. Biological degradation. Subject to chemical degradation. Aesthetics. Increased runoff.	Reapply annually. Must subgrade, underdrain. Eliminate contact with contaminants.
Polymer-Resins	No	Yes	Yes	None	Technique new; long term effect unknown. Requires frequent reapplication. Some are toxic while applying. Expected life @6 mo. Chemical reaction with waste unknown.	
Portland Cement	No	No	Yes	None	Will not prevent dust pollution.	

TABLE 14. SHORT TERM OBJECTIVE
TECHNICAL SCREENING RESULTS

SERIOUS LIMITATIONS:

- MULCH
- PLASTIC AND RUBBER SHEETING
- PORTLAND CEMENT
- WATER
- BENTONITE

SOME LIMITATIONS:

- SILICATES
- ASPHALT (BITUMINOUS)

FEW LIMITATIONS:

- LOCAL CLAY SOIL
- CONCRETE
- CRUSHED ROCK, GRAVEL
- ASPHALT (ASPHALTIC CONCRETE)

RESULT OF LONG TERM OBJECTIVE SCREENING

Analysis of the long term techniques confirmed the conclusion that none of the techniques could be used unconditionally by themselves. When ranking the long term techniques, each one was considered as the primary component of a potential solution. The ranking was accomplished in the same manner as with the short term objective techniques. Table 15 shows the ranking of the Long Term Objectives.

TABLE 15. LONG TERM OBJECTIVES

TECHNICAL SCREENING RESULTS

SERIOUS LIMITATIONS:

- SILICATES
- ASPHALT (BITUMINOUS)
- POLYMERS - RESINS
- PORTLAND CEMENT
- PLASTIC & RUBBER SHEETING

SOME LIMITATIONS:

- BENTONITE
- ASPHALT (ASPHALTIC CONCRETE)

FEW LIMITATIONS:

- LOCAL CLAY SOIL
- CONCRETE

PART VI. SCREEN REVIEW AND SELECTION OF ALTERNATIVES FOR DETAILED EVALUATION

SCREEN REVIEW

On June 20, 1980, BCD presented the results of the screening process at USATHAMA Headquarters. After thoroughly discussing the techniques with the least amount of limitations (Tables 14 and 15), it was concluded that: (1) all techniques to be considered for the short term objective should be compatible with the long term objectives. (2) only "natural" materials should be considered; (3) to accomplish the long range objectives, Basin A must be covered, and the primary component should be the clay soil available at RMA; (4) it would be necessary to utilize other natural materials in conjunction with the local clay soil to create a barrier to prevent the upward migration of contaminants into the clean soil and to further minimize downward percolation of water; (5) the barrier layer should be placed at a depth suitable to prevent penetration by roots or by prairie dog burrows. Penetration by either of these could destroy the long term integrity of the system.

SHORT TERM TECHNIQUES TO BE EVALUATED

Of all the techniques considered with a goal of eliminating the blowing of contaminated surficial soil, the two with the least amount of limitations were: local clay soil and gravel/crushed rock. Any of these could be applied on top of the contaminated soil and would stop the blowing of the contaminated soil. In addition, the application of these materials could be a step towards the long term solution.

SHORT TERM TECHNIQUES REJECTED

The use of mulch, plastic and rubber sheeting (liners), portland cement, water, bentonite, silicates, bitumimous asphalt, concrete and asphaltic concrete was rejected for the following reasons:

1) Mulch - could catch fire, blow away, wash away; requires continual maintenance.
2) Plastic and Rubber Sheeting (as a cover) - Rapid deterioration, difficult to anchor,easily punctured, torn.
4) Water - must be continually applied, would add to long term infiltration problem.
3) Portland Cement (as soil cement) - does not work for dust control.
5) Bentonite (as cover material) - must be kept moist. If the clay dries, it cracks and the cracks to not completely seal upon rewetting.
6) Silicates (as soil cement) - Deteriorate rapidly in weather conditions found at RMA. Rate of application and depth of penetration needed is unknown.
7) Bituminous Asphalt - Deteriorates rapidly, would require constant maintenance.
8) Asphaltic Concrete and Cement - require too much site preparation to be used as a short term solution.

LONG TERM TECHNIQUES TO BE EVALUATED

For accomplishing the long term objectives of minimizing the infiltration of water through Basin A, and maintaining dust control, there are two primary techniques to consider: (1) laying a concrete pad over the basin and (2) "sealing" the basin with local clay soil in combination with a barrier layer or layers.

A concrete pad is a consideration because it offers additional benefits such as use as a parking lot, for outdoor storage, or as the floor of warehouse buildings.

Two basic approaches to sealing the Basin with clay soil will be addressed. One creates a mound over the Basin and the other maintains the natural drainage patterns of the Basin. Each of these approaches will be studied in conjunction with each, or with combinations,of the barrier layers. Materials to be considered for the barrier layer(s) include bentonite clay and crushed rock or gravel.

LONG TERM OBJECTIVES REJECTED

The use of silicates, bituminous asphalt, polymers and resins, Portland cement, plastic and rubber sheeting (liners), and asphaltic concrete was rejected for the following reasons:

1) Silicates - do not prevent infiltration of water.
2) Bituminous Asphalt - reacts with organic waste, subject to breakdown from bacterial, chemical action.
3) Polymers and Resins - new concept, long term effect unknown. Some are in themselves toxic. Require frequent reapplication.
4) Portland Cement - will not work, rapid breakdown. As soil cement, will not stop percolation of water.
5) Plastic and Rubber Sheeting - must be covered, cannot be guaranteed longer than 5 years, extremely vulnerable to puncturing, cannot locate failures, lifetime unknown.
6) Asphaltic Concrete - expected life of 20+ years with proper maintenance.

Even though gravel, crushed rock, bentonite clay, and vegetation were "eliminated" during the screening processes, they were eliminated only as techniques that could be used by themsleves. These techniques are all viable when used in conjunction with the primary component. Gravel or crushed rock could be used to eliminate capillary movement of water upwards, bentonite is an excellent barrier to downward percolation (if covered and kept moist) and native vegitation is an excellent means of providing surficial erosion control.

Each of the techniques discussed in the sections Short Term Objectives to be Evaluated and Long Term Objectives to be Evaluated are throughly discussed in Part VIII of this report.

PART VII. CLIMATOLOGICAL CONDITIONS

The climatic parameters that have the greatest influence on the conditions at Basin A are the temperature, the precipitation, and the wind. The normal, mean, and extreme values for these three parameters are listed in Table 16. The data that were used to develop these values were collected at various stations in the Denver area over a period varying from 15 to 41 years. This information was used in a general way to evaluate the potential effects of these parameters on all the solution techniques and in a more specific way to determine the potential effects on the techniques identified as a result of the dual screening process. The specific conditions and problems that are, or may be, found at Basin A are discussed in Part VIII. The following brief discussions present the ways in which the three parameters may generally affect these conditions and problems.

TEMPERATURE

The temperature and the relative humidity have an effect on the evaporation and transpiration rates of the Basin A area. This in turn influences the infiltration rate and the direction of capillary movement. The movement of moisture in the soil is governed by the moisture potential according to the equation

$$q = -Kw \frac{\partial \Lambda}{\partial x}$$

where q is the flow per unit time through unit area normal to the direction of flow, x is distance along the line of flow, Kw is conductivity, and Λ is the potential. The conductivity has been shown to increase with moisture content and decrease with pore size. Thus capillary movement decreases as soil dries and is least in fine-grained soil.(1)

TABLE 16. METEOROLOGICAL DATA

Station: Denver Colorado Stapelton International AP Latitude: 39° 45' N Longitude: 104° 52' W

Standard Time Used: Mountain Elevation (ground): 5283 feet

NORMALS, MEANS, AND EXTREMES

Month	Temperatures, F							Precipitation Inches							Relative humidity %				Wind				
	Normal			Extremes				Water equivalent													Fastest mile		
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Hour 05 (Local Time)	Hour 11	Hour 17	Hour 23	Mean speed m.p.h.	Prevailing direction	Speed m.p.h.	Direction	Year
(a)				16		16			41		41		41		15	15	15	15	27	15	26	26	
J	43.5	16.2	29.9	69	1971	-25	1963	0.61	1.44	1948	0.01	1952	1.02	1962	62	45	48	62	9.3	S	46	SW	1969
F	46.2	19.4	32.8	76	1963	-18	1962	0.67	1.66	1960	0.01	1970	1.01	1953	67	44	43	66	9.3	S	49	NW	1953
M	50.1	23.8	37.0	84	1971	-4	1962	1.21	2.89	1944	0.13	1945	1.48	1959	69	42	41	65	10.0	S	53	NW	1952
A	61.0	33.9	47.5	84	1965	-2	1975	1.93	4.17	1942	0.03	1963	3.25	1967	69	38	34	59	10.4	S	56	NW	1960
M	70.3	43.6	57.0	93	1974	26	1972	2.64	7.31	1957	0.06	1974	3.55	1973	70	38	37	61	9.5	S	43	SW	1964
J	80.1	51.9	66.0	98	1971	36	1969	1.93	4.69	1967	0.10	1940	3.16	1970	72	38	37	62	9.1	S	47	S	1956
J	87.4	58.6	73.0	103	1973	43	1972	1.78	6.41	1965	0.17	1939	2.42	1965	71	36	36	59	8.6	S	56	SW	1965
A	85.8	57.4	71.6	100	1969	41	1964	1.29	4.47	1951	0.06	1960	3.43	1951	69	36	34	58	8.2	S	42	SW	1972
S	77.7	47.8	62.8	97	1960	20	1971	1.13	4.67	1961	T	1944	2.44	1936	71	40	36	63	8.2	S	47	NW	1955
O	66.8	37.2	52.0	87	1975	3	1969	1.13	4.17	1969	0.05	1962	1.71	1947	65	36	36	60	8.2	S	45	NW	1958
N	53.3	25.4	39.4	78	1973	-2	1961	0.76	2.97	1946	0.01	1949	1.29	1975	69	45	50	67	8.7	S	48	W	1962
D	46.2	18.9	32.6	73	1973	-18	1972	0.43	2.84	1973	0.04	1946	1.38	1973	66	45	52	65	9.0	S	51	NE	1953
YR	64.0	36.2	50.1	103	JUL 1973	-25	JAN 1963	15.51	7.31	MAY 1957	T	SEP 1944	3.55	MAY 1973	68	40	40	62	9.0	S	56	SW	JUL 1965

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 105 in August 1878; lowest temperature -30 in February 1936; maximum monthly precipitation 8.57 in May 1876; minimum monthly precipitation 8.57 in May 1876; minimum monthly precipitation 0.000 in December 1881; maximum precipitation in 24 hours 6.53 in May 1876; maximum monthly snowfall 57.4 in December 1913; maximum snowfall in 24 hours 23.0 in April 1885; fastest mile of wind 65 from West in May 1933.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.

NORMALS - Based on record for the 1941-1970 period.

DATE OF AN EXTREME - The most recent in cases of multiple occurrence.

PREVAILING WIND DIRECTION - Record through 1963.

WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.

FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

Source: National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, N.C.

PRECIPITATION

Precipitation normally goes to surface interception, infiltrates into the ground, runs off over the surface, and evaporates back into the air. The surface interception is a combination of depression storage and vegetative interception and depends on the topography and on the vegetative cover. The infiltration rate depends on the permeability and the moisture content of the soil. Surface runoff is the remainder of the precipitation, that has not been intercepted or infiltrated. Evaporation primarily occurs after a rainfall and affects intercepted water and the moisture content of the soil surface.

Precipitation has several effects on the environment. The impact of raindrops tends to decrease infiltration into the soil. The surface runoff is slightly increased by this and may cause increased surface erosion and flooding beyond normal levels.

WIND

The surface erosion caused by the wind has several harmful effects. Topsoil may be removed at a location which would decrease the ability of vegetation to establish itself. Scouring and abrasion of objects such as buildings, cars, etc. may occur if the soil particles are forcefully blown by the wind. Breathing and health-related problems may occur if fine soil particles are prevalent in the air. This problem is particularly important at RMA because of the contaminated soil in Basin A. The prevailing strength and direction of the wind have a strong bearing on the effectiveness of different proposed solutions and must be considered carefully.

In the following part of this report the solution options that passed the screening process are described in more detail. In addition, the conditions in the area and the problems they cause are discussed.

PART VIII. TECHNIQUES GIVEN DETAILED EVALUATION

GENERAL DISCUSSION OF TECHNIQUES

The short-term and the long-term techniques that "passed through" the screening process are described in this section in general terms. More technical detail is presented in the section entitled impact of climatological conditions.

The short-term options reflect two constraints: (1) they must be effective and reliable over 2 to 3-year period and (2) they must be compatible with potential long-term solution techniques. Two options meet these requirements ; both of which involve covering the surface with a material layer and both of which address only the wind erosion problem. One option is to place a layer of local clay-soil over the entire basin; the other option is to use a layer of gravel/crushed-rock. Neither of these options prevents the infiltration of precipitation into the underlying soil and both have some limitations associated with their use. These limitations are discussed after the description of the long-term techniques.

There are two primary techniques which would accomplish the long term objectives at Basin A. The first would resolve the Basin A wind erosion and infiltration problem by covering the Basin surface with a layer of concrete. The second technique entails covering the Basin surface with one or more layers of local soil, gravel, and/or bentonite clay.

Concrete

The concrete layer technique would effectively eliminate wind erosion and infiltration on both a short term and long term basis provided that routine maintenance is performed. If the concrete was poured in large flat slabs it could be used as the foundation for buildings, warehouses, outdoor storage areas, or parking lot(s) as a secondary benefit to the primary objectives. Problems associated with this concept are serious, however, and are discussed in the next section.

Soil, Barrier Layer(s)

This technique involves covering the Basin surface with one or more layers of local soil, gravel, and/or bentonite clay. Within this technique there are two separate approaches: one approach involves following the existing contours and maintaining a concave Basin profile and the other approach involves filling in the Basin to produce a convex profile. Within each of the approaches there are a number of layering versions which differ according to the number and placement of the layers of soil, gravel, or clay. The concave and convex approaches and associated versions are presented in Figures III and IV and Tables 17 and 18.

TABLE 17. SOIL, BARRIER LAYER TECHNIQUE, POTENTIAL LAYERING VERSIONS, CONCAVE APPROACH

VERSION	A	B	C	D
Layer				
1	S	S	S	S
2	G	L	G	L
3	L	G	L	S
4	G		S	

KEY:
S = Local Soil
G = Gravel
L = Bentonite Clay

TABLE 18. SOIL, BARRIER LAYER TECHNIQUE, POTENTIAL LAYERING VERSIONS CONVEX APPROACH

VERSION	E	F	G
Layer			
1	S	S	S
2	L	L	G
3	G	S	L
4	S		S

KEY:
S = Local Soil
G = Gravel
L = Bentonite Clay

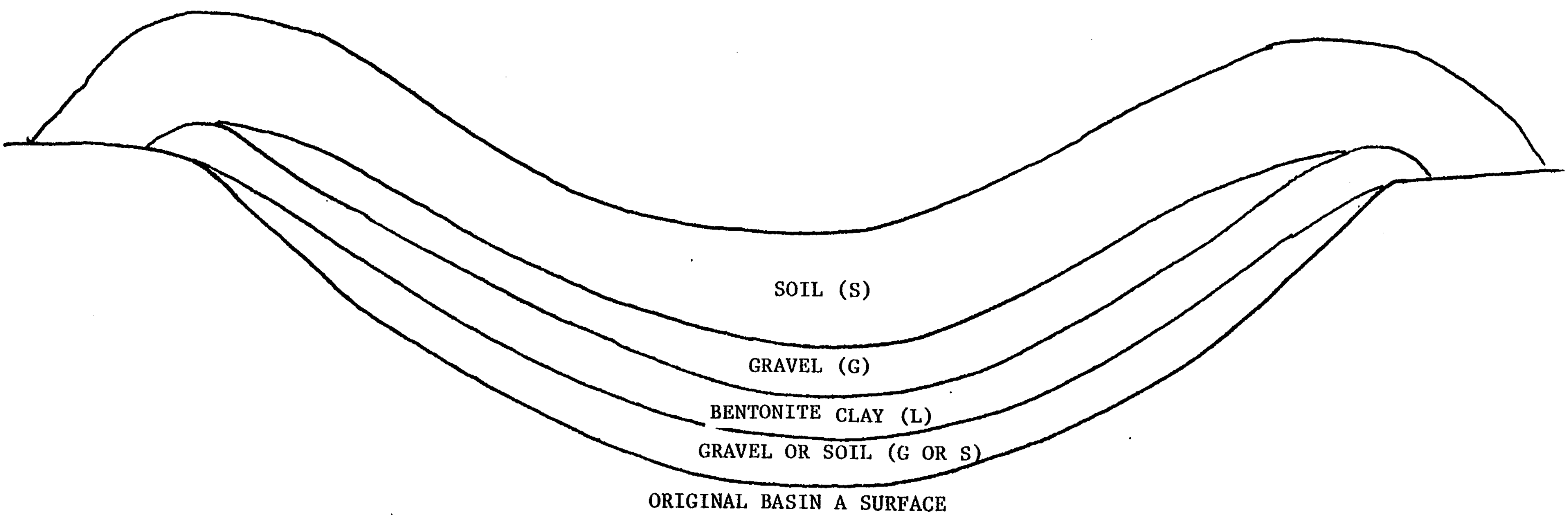

FIGURE III. SOIL, BARRIER LAYER TECHNIQUE CONCEPTUALIZED CONTOUR PROFILE, POTENTIAL CONCAVE LAYERING VERSIONS

Not to Scale

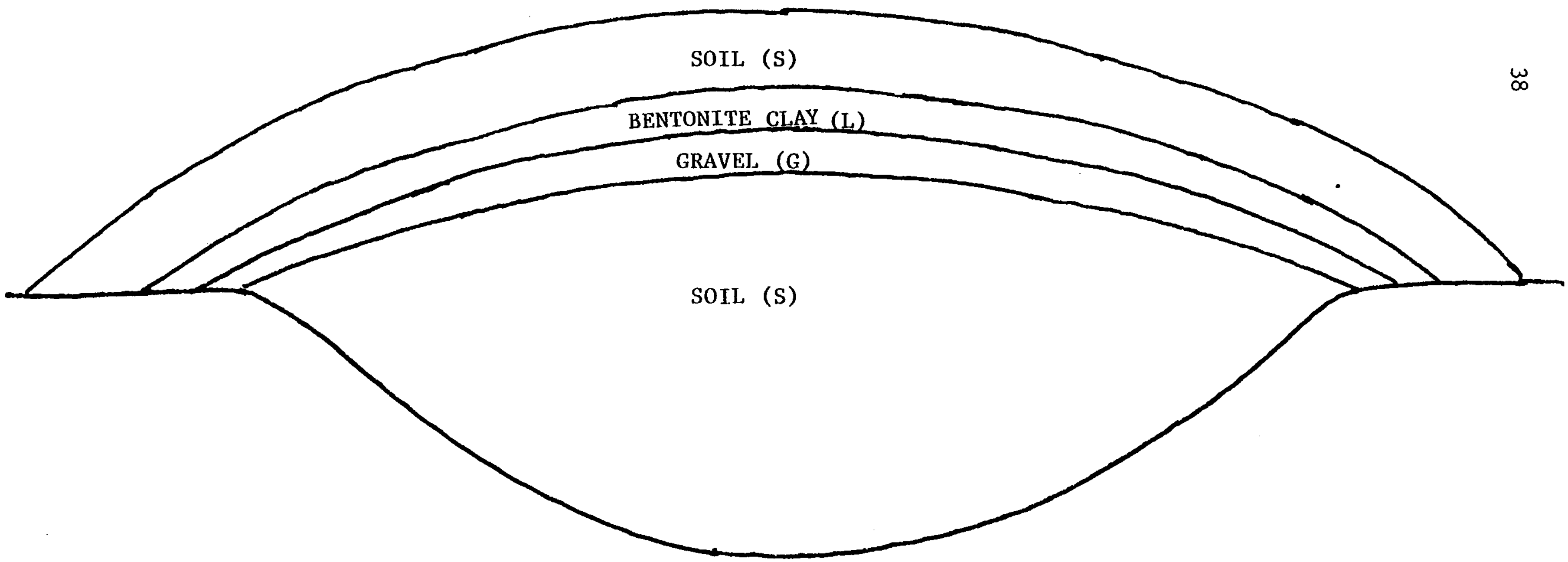

FIGURE IV. SOIL, BARRIER LAYER TECHNIQUE CONCEPTUALIZED CONTOUR PROFILE, POTENTIAL CONVEX LAYERING VERSIONS

Not to Scale

The concave and convex approaches would both use several layers of soil, gravel, and clay to achieve the long term objectives of this study. Each layer has a specific role to play in the minimization of wind erosion and infiltration.

The purpose of the bentonite clay layer is to form a barrier which will minimize downward percolation of precipitation and upward migration of contaminants. By itself, however, the clay may be subject to weathering and to possible damage from chemicals in the groundwater. A gravel/crushed rock barrier under the clay liner would serve the purpose of reducing or eliminating capillary action that could conceivably carry contaminants upward to contact the clay. A soil layer on top of the clay layer would help to maintain the moistness of the clay and hence its integrity, and would keep the clay from blowing away, which it would do if it were exposed to the elements and allowed to dry out. The soil would also provide protection from prairie dog burrowing and disruption from vegetation roots. The soil itself would be retained with shallow-rooted vegetation which would minimize wind and rain erosion. An additional gravel/crushed rock layer could be placed over the bentonite clay under the surface soil. This gravel/crushed rock layer would improve the drainage characteristics if excess infiltration of water occurred.

IMPACT OF CLIMATOLOGICAL CONDITIONS

Infiltration, Evaporation, and Runoff

Infiltration

Here it is shown that 5 feet of soil at RMA will absorb all of the rain from a worst case storm (3.55 inches in a 24 hour period - see Table 16). The porosity of the soil at Basin A is assumed to be 40 percent (see Table 19), with the voids distributed evenly in all directions.

TABLE 19. RANGE OF VALUES OF POROSITY

	Porosity %
Unconsolidated deposits	
Gravel	25-40
Sand	25-50
Silt	35-50
Clay	40-70
Rocks	
Fractured basalt	5-50
Karst limestone	5-50
Sandstone	5-30
Limestone, dolomite	0-20
Shale	0-10
Fractured crystalline rock	0-10
Dense crystalline rock	0-5

Source: Groundwater, by J. A. Cherry and R. J. Freeze, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Soil permeabilities in Basin A range from 5.14×10^{-4} cm/sec to 4.44×10^{-7} cm/sec (Table 20). Permeabilities in this range are considered to be low to very low (Table 21).

TABLE 20. RMA-BASIN A AREA LABORATORY TEST RESULTS

LABORATORY TEST RESULTS

Boring No.	WES ID No.	Sample Depth, ft	Formation Sampled	Soils Classification	Pretest Water Content, %	Pretest Dry Density, lb/ft^3	Permeability Test Method	Confining Pressure, $lb/in.^2$	Permeability, cm/sec
718	CIP	17.3-18.8	Alluvium	SM	19.3	105.7	Falling Head	8.0	1.15×10^{-4}
723	--	38.4-39.1	Denver	CL	15.6	112.8	Falling Head	25.0	5.09×10^{-6}
723	--	50.0-51.3	Denver	SM	16.9	106.1	Falling Head	28.0	2.74×10^{-6}
723	--	50.0-51.3	Denver	SM	15.7	107.5	Falling Head	28.0	4.57×10^{-6}
723	--	50.0-51.3	Denver	SM	13.0	102.7	Constant Head	28.0	2.97×10^{-4}
724	--	30.1-31.6	Denver	SM	9.5	101.9	Falling Head	22.0	1.31×10^{-4}
725	--	22.6-22.9	Alluvium	CL	21.1	104.4	Falling Head	16.0	4.44×10^{-7}
725	--	23.3-23.6	Allumium	CL	18.5	108.9	Falling Head	16.0	2.68×10^{-6}
726	G4P	11.1-11.7	Allumium	SM	14.5	111.1	Falling Head	8.0	1.16×10^{-4}
730	H3P	13.0-15.1	Alluvium	SM	17.5	108.1	Constant Head	10.0	2.60×10^{-5}
730	H3P	53.0-53.5	Denver	SP-SM	14.8	102.1	Falling Head	22.0	5.14×10^{-4}
730	H3P	53.9-54.3	Denver	SP-SM	19.9	102.8	Falling Head	22.0	4.02×10^{-4}
732	G3P	17.9-;9.2	Allumium	SM	23.7	99.1	Falling Head	14.0	1.84×10^{-6}
734	G5P	28.3-29.0	Alluvium	SP-SM	9.3	104.0	Constant Head	17.0	4.37×10^{-4}
741	H4P	10.0-10.2	Alluvium	SC	24.6	97.0	Falling Head	6.0	5.83×10^{-6}
741	H4P	10.0-10.7	Alluvium	SM	15.1	103.3	Falling Head	6.0	6.16×10^{-4}
741	H4P	17.6-18.1	Alluvium	CL	21.3	102.6	Falling Head	9.0	6.26×10^{-6}

Source: "Geology and Groundwater Definition, Basin A Area, Rocky Mountain Arsenal, Denver, Colorado", by J. D. Broughton, W. D. Miller, and G. B. Mitchell, U.S. Army Engineer Waterways Experiment Station, June, 1979.

TABLE 21. RELATIVE VALUES OF PERMEABILITY

Relative Permeability	Values of k, cm/sec	Typical Soil
Very permeable	Over 1×10^{-1}	Coarse gravel
Medium permeability	1×10^{-1}-1×10^{-3}	Sand, fine sand
Low permeability	1×10^{-3}-1×10^{-5}	Silty sand, dirty sand
Very low permeability	1×10^{-5}-1×10^{-7}	Silt, fine sandstone
Impervious	Less than 1×10^{-7}	Clay

Source: Introductory Soil Mechanics and Foundations by G. B. Sowers and G. F. Sowers, Third Edition, Macmillan Publishing Company, Inc.

Assuming the infiltration rate is equal to that of the most permeable soil thus far identified at RMA (6×10^{-4} cm/sec, see Table 20), further assuming the maximum 24 hour rain of record (3.55 inches in 24 hours, Table 16), and assuming that the rain intensity is constant over the 24 hour period, the following "worst case" conditions result:

Rain intensity = 0.148 in./hr

Permeability = 0.850 in./hr

Because the permeability is greater than the rain intensity, all the rain would infiltrate, except for the amount that was intercepted by vegegation, which would be minimal in a semiarid area with little foliage such as RMA. Assuming no evaporation, and based on the above assumed porosity, if the full 3.55 inches of rain infiltrated and the soil pores were completely dry, 8.9 inches of soil depth would be saturated with water. However, considering that gravity will continue to exert an attraction on the soil moisture and cause it to percolate and considering that completely dry pore spaces are rare, the depth of penetration of the water would be greater than 8.9 inches. Assuming a 50 percent existing moisture content would result in the saturation of 17.8 inches of soil. Even if gravity acts to double or triple this depth, only 3 to 4-1/2 feet of soil would contain water. With 5 feet of cover soil, the soil zone immediately above the clay liner would not be saturated and therefore a gravel drainage layer would not be required.

Since the scenario presented here is a worst case situation, the actual infiltration rates and depths of water penetration would be much less. With evapotranspiration acting to dry the soil and pull water upward due to capillary action, with an actual soil permeability of 10^{-5} to 10^{-6} cm/sec (Table 20), and with a more typical load of 1/2 to 1 inch of precipitation in 24 hours, a saturated soil zone will be thin and most likely temporary.

Bentonite clay has a permeability of less than 1 x 10^{-7} cm/sec (.000142 in./hr). In relative terms this is considered impervious (Table 21). Any water that percolated through the soil cover, assuming local areas of worst case permeability, or during a 500 or 1000 year storm event, would be held above a bentonite clay barrier where it would be subject to evapotranspiration.

Evaporation

Lack of appropriate data prevents the calculation of the daily evaporation rates at RMA. However, a U.S. National Weather Service figure (Figure V) indicates that the average annual evaporation in the central part of Colorado is about 42 inches per year from shallow lakes.

Because evaporation from surface soils is comparable to evaporation from shallow lakes or ponds, this average value may be used to predict the average evaporation from Basin A surface area. By comparing an evaporation rate of 42 inches per year with an average annual precipitation rate of 15.51 inches per year, it becomes readily apparent that there is a very strong tendency for the near-surface water that has penetrated the soil to be removed. Computer modeling of groundwater flow at RMA (calibrated during observed data) indicates that a 10 percent recharge rate to groundwater occurs under existing conditions.* It is not anticipated that this much recharge will occur in the Basin A area if the existing areas of ponded water are eliminated.

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*Written communication from Allan McKinney, USATHAMA COTR.

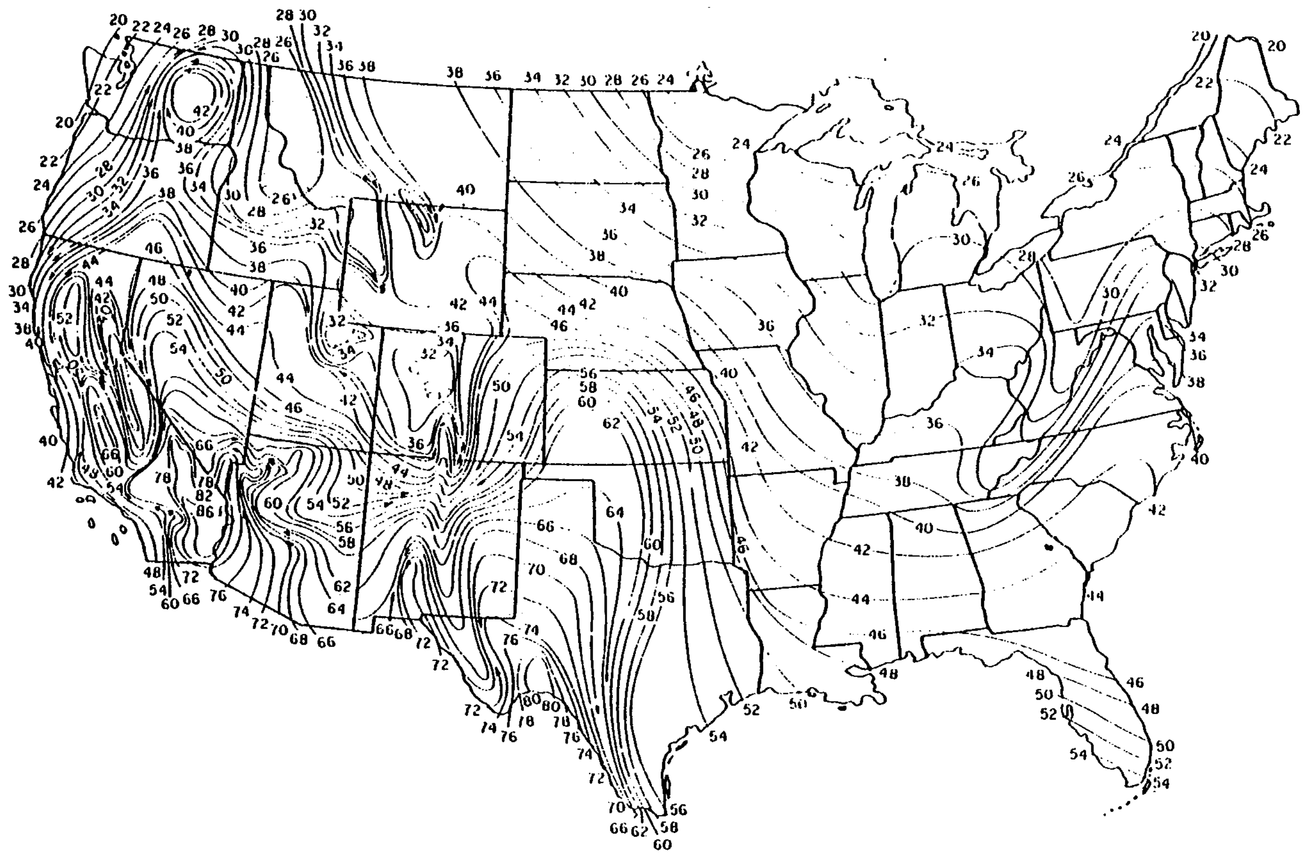

FIGURE V. AVERAGE ANNUAL EVAPORATION (INCHES) FROM SHALLOW LAKES (U.S. NATIONAL WEATHER SERVICE)

Source: <u>Hydrology for Engineers</u>, by R. R. Limsley, Jr., M. A. Kohler, and J. L. Paulhus, 2nd Edition, McGraw-Hill Book Co. (1975).

Runoff

Unlike the worst case situation described in the section on Infiltration (pp 40-43), most of the annual precipitation occurs during intense summer thunderstorms.

Because of the low soil permeabilities and the concomitant low infiltration rates, most of this precipitation will result in surface runoff. If local soils are used for the short and the long term techniques, anticipated runoff volumes should not be significantly different from current runoff volumes. Establishment of a vegetative cover over the soil would result in a net reduction of runoff volume.

Short Term Techniques

Local Clay Soil

The short term technique of using local clay-soil for a surface cover layer has only one potential drawback. This relates to possible wind and/or water erosion which could reexpose portions of the original Basin A soil. Because of the moderate local wind speeds (which average 9 m p h) and the low rainfall (which averages 15 in./yr), reexposure is not expected to be a serious concern, assuming that the soil cover layer is properly engineered and applied. A good wind erosion control measure involves establishing vegetation on the soil, but plants could take more time to become established adequately than the length of time that the short-term technique is in effect. The problem of infiltration through the cover layer is not addressed by the short term objectives, but the similarity of the existing Basin soil and the cover soil should result in runoff and infiltration rates similar to those currently existing.

Gravel/Crushed Rock

The short term technique of using a gravel/crushed rock layer eliminates the dust problem, but the infiltration of water would be exacerbated. This reversal of the problems associated with the use of a local clay-soil cover is due to the relative characteristics of the two cover layers.

Gravel/crushed rock has large pore spaces which trap precipitation and allow more time for it to infiltrate into the soil. The larger size of the gravel/crushed rock compared to the soil particles means that wind and runoff must be very powerful to move them and such conditions do not often occur at RMA. Therefore, blowing dust and erosion are minimized or eliminated. The ability of the gravel pores to transmit water is a feature which is further evaluated in the following section on long term techniques.

Long Term Techniques

Concrete

The first option considered here is the concrete pad technique. The major attractive feature of this option, in addition to solving the wind erosion and infiltration problem, is its potential utility as a foundation for buildings, parking lots, etc. However, major subgrading of the Basin A area would be required. As a consequence of the leveling and grading of the Basin, safety and healty problems due to large-scale movement and mixing of contaminated materials would tend to make this option less attractive. The difficulty in finding enough uses for 280 acres of concrete pads would also be a negative factor. A further consideration is the greatly increased runoff volume that would result from such an extensive impermeable surface. The low average rainfall of the area indicates that this would not normally be a significant problem. However, a severe thunderstorm could lead to large quantities of runoff; a 1-inch rain on the 280-acre site would produce more than 7.6 million gallons of water. A final factor is thermal updraft and heat distortion that could disturb flights landing and taking off at Stapleton Airport. The periods of high average temperature in the summer and high incident solar radiation could produce a strong thermal air current over the Basin as well as cause visual problems due to heat distortion. These effects are difficult to quantify, but must be considered.

Soil, Barrier Layers

Concave Profile Versions. There are four versions of the concave approach to be considered (see Table 17). Versions A and C are identical

except for the bottom layer which is gravel in A and soil in C. The same difference exists between Versions B and D. In addition, the difference between A and B and between C and D is the presence or absence of a gravel layer overlying the clay liner. The reasons for the differences and similarities and their relationships to the site conditions are presented herein.

A gravel/crushed rock layer applied directly on top of the Basin A soil in versions A and B is one of the two options considered for the short term objective solution. As part of a long term technique its purpose would be to prevent the upward migration of contaminated groundwater due to capillary action. Testing at RMA has indicated that the permeability of bentonite clay is not increased by reaction with the chemicals found in Basin A*. Therefore, the liner could contact the basin surface directly and still maintain its integrity. Unless a gravel/crushed rock layer is overwhelmingly superior to a soil layer as a short-term solution, it is not proposed as the bottom layer. This consideration would eliminate Versions A and B from those under consideration since it would not be necessary to isolate the bentonite clay layer from the contaminated soils.

The purpose of a gravel/crushed rock layer above the bentonite clay barrier (Versions A and C) is to intercept excess infiltrated water. In the section on infiltration, it was established that there will not be an excess of infiltrated water if 5 feet of local clay soil is applied over the bentonite. Some moisture above the clay is desirable and necessary to maintain the particle swelling in the clay that results in low permeabilities. A gravel layer would tend to drain this necessary moisture and would thus conflict with the long range objective. Therefore, Version C is not further considered.

The remaining version of the concave approach is Version D. The bottom soil layer would be necessary only to satisfy the short term objective; it serves no essential function in the long term technique. The clay barrier serves to prevent upward and downward percolation of water, as it does in all versions.

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*Verbal communication with Allan McKinney, USATHAMA COTR.

Convex Profile Versions. The three versions of the convex approach (Table 18) are similar to those of the concave approach. Both of the versions with gravel layers, Versions E and G, may be eliminated from consideration for the same reasons given in the previous discussion of Versions A, B, and C. This leaves Version F, which is identical to Version D, except that in version F a large amount of soil must be applied between the bentonite clay layer and the in-place contaminated soil. The purpose of the applied soil layer would be to create the convex profile.

BCL originally considered the convex profile because it was believed that an improperly designed concave approach could result in the formation of depressions which would encourage the infiltration of water. The rationale for having a convex profile was that runoff would be directed outward and could therefore not collect and infiltrate into the soil.

After consideration of the expected infiltration rate through the local soil cover and bentonite clay, BCL believes that the concave approach should be more than adequate. The large additional volume of local soil needed to form the convex profile will not be necessary.

In all versions under consideration in both the concave and convex approaches, the purpose of the soil above the bentonite clay is to provide protection against drying and subsequent cracking of the bentonite clay and to regulate the water balance in and out of Basin A. As discussed in the sections Infiltration and Evaporation, a 5-foot soil layer will permit slow infiltration during precipitation events, and the dry climatic conditions and associated high evaporation rate will result in an even loss of the infiltrated water. Rapid runoff and resultant flooding would be minimized.

Establishment of native shallow rooted vegetation on the final soil cover layer is necessary to prevent long term wind and water erosion. Trees, bushes, and other phreatophytes must not be permitted to grow over the Basin because their root systems could grow into and through the bentonite clay barrier. While the plants were living, toxic substances could be absorbed from the contaminated soil beneath the barrier and transported to the surface. After the plants died, the root systems would decay and result in "channels" in the barrier through which water could travel.

The establishment of vegetation on the final cover soil has one adverse effect - the local prairie dog population will be attracted if the

goals of the long term objective are achieved. Prairie dogs currently abound in the area surrounding the limits of Basin A but they have not burrowed in the Basin area because of the contaminants in the soil and associated lack of vegetation. Prairie dog burrows are typically 3 to 4 feet deep but may go deeper.

The application of 5 feet of uncontaminated soil cover over the bentonite clay barrier is a minimum if the Soil, Barrier Layer technique is to be implemented. This soil depth allows a margin of insurance in preventing root penetration and/or destruction of the barrier integrity by prairie dog burrows. However, establishment of deep rooted plants and burrowing by prairie dogs should be discouraged.

MATERIAL REQUIREMENTS AND COSTS AND CONSTRUCTION COSTS

This chapter of the report defines the amount and cost of each material needed to implement the long term objective versions described in the previous section (Specific Conditions and Problems). Material requirements are addressed, followed by sections on material costs, construction costs, and total costs.

Before determining the amount of each material required, it was necessary to define the area of Basin A. The limits of the study are defined* by the 5245-foot contour elevation line on Figure VI. Added to the area within this contour line were the areas utilized by Shell Chemical Company for drum storage/burial and the lime settling basins. The area within the boundaries of this study is conservatively calculated at 280 acres and probably includes areas of relatively low contamination levels.
The following assumptions were made in order that calculations of material volume requirements could be made:

- The area to be covered in both the convex and concave solutions is 280 acres.
- Each individual "layer" utilized in the concave solution is of a uniform thickness over the entire 280-acre area.

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*Defined during RMA site inspection and meeting on May 8 and 9, 1980.

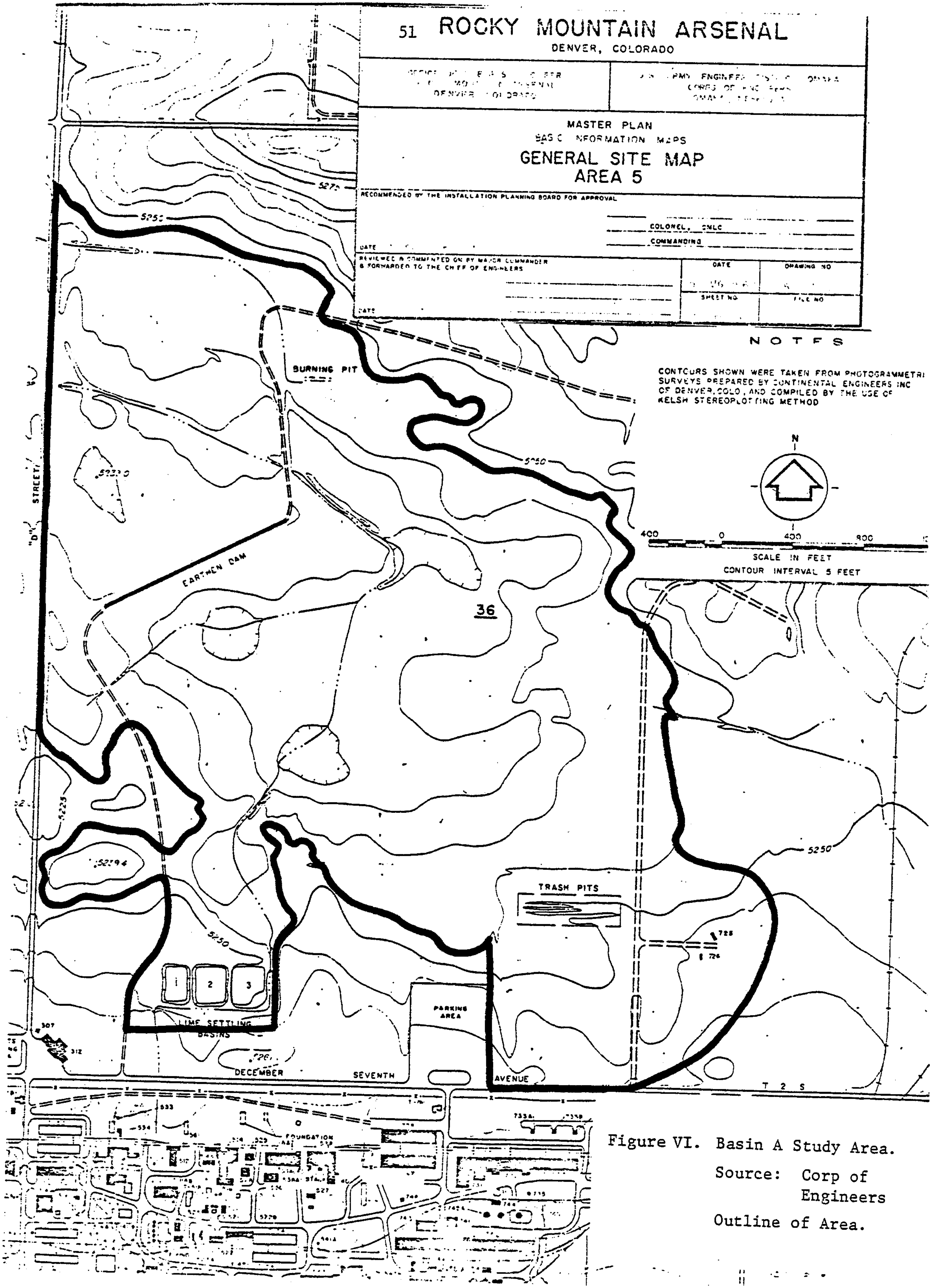

Figure VI. Basin A Study Area.

Source: Corp of Engineers

Outline of Area.

- For all convex solutions, the amount of material required to fill Basin A and create a mound was estimated from topographic maps. All overlying "layers" are assumed to be of uniform thickness over the entire area.
- The basin is cone shaped with a depth of 16 feet.
- The surface-soil layer is 5 feet thick in both the concave and convex approaches.
- The gravel/crushed rock layer is 6 inches thick in all versions where it is utilized.
- The initial, short term objective soil layer is 1 foot thick.
- Bentonite clay is applied at a rate of 2 pounds/square foot (42 tons/acre).
- The specific gravity is 2.2 for the local soil and 2.7 for gravel/crushed rock.
- The concrete thickness in the long term concrete pad solution is 4 inches.
- Two million cubic yards must be graded for concrete placement.
- The local clay-soil weighs 3000 pounds/cubic yard.
- Gravel/crushed rock weighs 3000 pounds/cubic yard.
- Bentonite clay weighs 2000 pounds/cubic yard.

Material Requirements

Concave Approach, Version A

This version would utilize (from bottom to top) a layer of gravel, bentonite, gravel, and final soil cover. Material requirements are:

- soil cover - 4,186,000 tons
- gravel/crushed rock - 1,027,000 tons
- bentonite clay - 11,760 tons.

Concave Approach, Version B

This version would utilize a layer of gravel, bentonite, and soil cover. Material requirements are:

- soil cover - 4,186,000 tons
- gravel/crushed rock - 514,000 tons
- bentonite clay - 11,760 tons.

Concave Approach, Version C

This version would utilize a layer of bentonite, gravel, and soil cover. Requirements are the same as in Version B.

Concave Approach, Version D

This version would utilize a layer of bentonite covered by the soil cover layer. Requirements are:

- bentonite clay - 11,760 tons
- soil cover - 4,186,000 tons.

Convex Approach, Version E

This version would require (from bottom to top) soil to fill in the basin and create a slight mound, covered by layers of gravel, bentonite clay, and cover soil. Material requirements are:

- gravel/crushed rock 514,000 tons
- bentonite clay - 11,760 tons
- cover soil - 4,186,000 tons
- fill soil - 4,465,000 tons
- total soil - 8,651,000 tons.

Convex Approach, Version F

This version would require enough fill soil to create a slight mound in place of the Basin A depression, a layer of bentonite clay, and cover soil. Material requirements are:

- bentonite clay - 11,760 tons
- fill soil - 4,465,000 tons
- cover soil - 4,186,000 tons.

Convex Approach, Version G

This version would be the same as Version E, except that the bentonite clay would be placed under the gravel/crushed rock.

Concrete Pad Approach

This would cover Basin A with a 4-inch-thick layer of concrete and would require 150,578 cubic yards of concrete.

Material Requirements Summary

Table 22 summarizes the amount of each material required to implement each of the approaches.

TABLE 22. MATERIAL REQUIREMENTS SUMMARY
(Tons of Material)

	Concave Approach				Convex Approach	
Version:	A	B	C	D	E/G	F
Soil	4,186,000	4,186,000	4,186,000	4,186,000	8,651,000	8,651,000
Gravel/ Crushed Rock	1,027,000	514,000	514,000		514,000	
Clay	11,760	11,760	11,760	11,760	11,760	11,760

Concrete Pad--150,578 cubic yards.

Material Costs

Local Denver area vendors were contacted to obtain current (June 1980) prices for gravel/crushed rock and concrete. The International Minerals Corp was contacted for price information and shipping cost for bentonite clay.

Table 23 lists the material cost per ton (concrete cost/cubic yard), cost of delivery per ton (cubic yard), and total cost per ton (cubic yard).

TABLE 23. MATERIAL AND SHIPPING COSTS

Material	Material, $/ton	Shipping, $/ton	Total, $/ton
Bentonite Clay	$40.50	$42.71*	$83.21
Crushed Rock/Gravel	$ 6.93	$ 6.00	$12.93
Concrete			$45.00/cu yd

*Shipped fron Colony Wyoming (closest source of Bentonite) by rail. Includes a 1.2 percent fuel adjustment clause.

It is assumed that sufficient volumes of suitable soil materials can be obtained from within the boundaries of RMA at no material expense, and without creating unacceptable surface or subsurface disturbances.

The total amount of each material needed was multiplied by the total (material plus shipping) cost per ton to give the total cost of each material needed. Table 24 displays this information.

TABLE 24. TOTAL MATERIAL COST FOR EACH APPROACH

		Versions					
Material	Concrete	A	B	C	D	E/G	F
Concrete	$6,776,000	—	—	—	—	—	—
Bentonite Clay	--	$979,000	$979,000	$979,000	$979,000	$979,000	$979,000
Gravel/ Crushed Rock	--	$13,279,000	$6,646,000	$6,646,000	—	$6,646,000	—
Soil	--	*	*	*	*	*	*

*Soil costs available at RMA.

Construction Costs

The previous two sections deal with the cost of obtaining materials and the cost of having them delivered to RMA. This section deals with the cost of placement of materials, compaction, earth hauling, grading, placing concrete, and construction crews needed for the tasks. All of the data for this section were obtained from the Means Building Construction Cost Data 1978.

The 1978 figures were updated to 1980 by assuming a 9 percent annual inflation rate. Pertinent data extracted from this manual are presented in Appendix D.

Table 25 shows the cost of hauling enough local soil to implement Versions A through G (volumes shown as tons in Table 23 have been converted to cubic yards). Costs for hauling 1 mile and 4 miles are shown.

TABLE 25. SOIL HAULING COST*

Version	Cubic Yards (c.y.)	\$/c.y. (1 mile)	\$/c.y. (4 miles)	\$/mile	\$/4 miles
A, B, C, D	2,790,700	\$0.75	\$1.26	\$2,093,000	\$3,516,000
E, F, G	5,767,300	\$0.75	\$1.26	\$4,325,0000	\$7,267,000

* Means Building Construction Cost Data 1978, updated to 1980 dollars.

Table 26 illustrates the cost of placing the materials in Versions A through F.

TABLE 26. MATERIAL PLACEMENT COST*,**

Version	Soil, cubic yards	Gravel/Crushed Rock, cubic yards	\$/cubic yard	\$
A	\$2,790,700	684,700	\$1.65	\$ 5,734,000
B	2,790,700	342,300	1.65	5,169,000
C	2,790,700	342,300	1.65	5,169,000
D	2,790,700	—	1.65	4,604,655
E/G	5,767,300	342,300	1.65	10,081,000
F	5,767,300	—	1.65	9,516,000

*includes hauling costs

**These data were obtained from Means Building Construction Cost Data 1978 updated to 1980 dollars and do not reflect additional costs that might be incurred as a result of working in a hazardous environment. Material placement in a hazardous environment could add additional cost.

Table 27 shows the cost of compacting the local clay soil, if compaction is necessary.

TABLE 27. SOIL COMPACTION COST*

Version	Cubic Yards	$/Cubic Yard	$
A, B, C, D	2,790,700	$1.10	$3,070,000
E. F, G	5,767,300	$1.10	$6,344,000

*Means Building Construction Cost Data 1978 updated to 1980 dollars.

Tables 28 and 29 respectively show the cost of site preparation (grading) and concrete placement.

TABLE 28. GRADING COST FOR CONCRETE PLACEMENT*

Dozen Cost, $/cubic yard	Scraper Cost, $/cubic yard	Material Volume, cubic yards	Total Cost, $
$1.22	$1.30	2,000,000	5,040,000

*Means Building Construction Cost Data 1978 updated to 1980 dollars.

TABLE 29. COST OF CONCRETE PLACEMENT*

Installation Cost, $/cubic yard	Material Volume, cubic yards	Total Cost
$45.00	150,578	$67,800

*Means Building Construction Cost Data 1978 updated to 1980 dollars.

Total Cost of Each Approach

Table 30 summarizes the cost of purchasing, hauling, placing and compacting (where necessary) each of the materials. The total estimated cost of implementing each version of the long term objectives is shown across the bottom of the chart.

TABLE 30. COMBINED MATERIAL AND CONSTRUCTION COSTS

	Versions							
Costs	Concrete	A	B	C	D	E	F	G
Concrete								
Material/ Transportation	$6,776,000	–	–	–	–	–	–	–
Grading	$5,040,000	–	–	–	–	–	–	–
Placement	$ 68,000							
Soil								
Material	–	–	–	–	–	–	–	–
Placement	–	$4,605,000	$4,605,000	$4,605,000	$4,605,000	$9,516,000	$9,516,000	$9,516,000
Compaction	–	$3,070,000	$3,070,000	$3,070,000	$3,070,000	$6,344,000	$6,344,000	$6,344,000
Gravel/Crushed Rock								
Material	–	$13,279,000	$6,646,000	$6,646,000	–	$6,646,000	–	$6,646,000
Placement	–	$1,130,000	$565,000	$565,000	–	$565,000	–	$565,000
Bentomite Clay								
Material	–	$979,000	$979,000	$979,000	$979,000	$979,000	$979,000	$979,000
Placement	–	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
TOTALS	$11,884,000	$23,083,000	$15,885,000	$15,885,000	$8,674,000	$24,070,000	$16,859,000	$24,070,000

PART IX. CONCLUSIONS

There are two objectives included in the scope of this Basin A study: the short term objective of stabilizing the soil to eliminate windblown contamination (if present) and the long term objective of minimizing the leaching of water through Basin A into the underlying groundwater, while maintaining control of potential windblown contaminants.

SHORT TERM OBJECTIVE

If it becomes necessary to implement control measures to meet the short term objective, BCL recommends the application of uncontaminated local clay soil (available on RMA property) over the entire contaminated area of Basin A. The thickness of the application will depend upon how long it is designed to last. The cost of the application in turn depends upon the thickness of clay applied. Both control techniques recommended below for meeting the long term objectives will also meet the short term objective.

LONG TERM OBJECTIVE

Of all the techniques examined, BCL finds two which can be expected to meet the long term objectives: a concrete cover and a bentonite cover over the entire basin. The choice between the two will depend on the projected uses of RMA.

The concrete cover involves grading the entire basin and applying a 4-inch pad of concrete. Estimated cost of this technique would be $11,884,000. The advantage of this approach is that the concrete pad could be used as outdoor storage space, as parking area(s), or for warehouse floor space, any of which could help defray the expense of installation and maintenance. Disadvantages are that regular maintenance would be necessary to keep all joints and settling cracks sealed, and that the concrete cover has an anticipated life of only 50 years.

The bentonite cover requires grading the basin (maintaining existing drainage) to eliminate the three water-filled depressions, applying bentonite clay over the entire basin at a rate of 42 tons per acre, and covering the bentonite with 5 feet of local clay soil. Total cost of this approach is estimated at $8,674,000. The advantage of this technique is that it should last indefinitely with very little maintenance. Deep rooted vegetation should be eliminated and prairie dogs should be discouraged from inhabiting or burrowing in the Basin area.

Projected cost data are based upon the cost of materials and delivery (shipping) charges, and assumes that all construction work will be performed by private contractors.

APPENDIX A

ROCKY MOUNTAIN ARSENAL
BACKGROUND DOCUMENTS

APPENDIX A

1) Anon.,"Basin A Neck Area, Rocky Mountain Arsenal Contamination Survey", no date (Draft).

2) Little, Arthur D., Inc. "State-of-the-Art Survey of Land Reclamation Technology", May 1976.

3) Black & Veatch Consulting Engineers, "Memorandum Report Sanitary Sewerage System Repairs, Rocky Mountain Arsenal", October 1979.

4) Broughton, J.D., Miller, W.D, Mitchell, G.B., "Geology and Groundwater Definition, Basin A Area, Rocky Mountain Arsenal, Denver, Colorado", Geotechnical Laboratory U.S. Army Engineer Waterways Experiment Station, June 1979 (Draft).

5) Cogley, David R., "Report on OTSG Coring Data for Compounds at Rocky Mountain Arsenal", Walden Div. of ABCOR Inc., Nov. 1976.

6) Kolakowski, Jan E., "Migration Potential of Contaminants in the Soil of Rocky Mountain Arsenal", Process Technology Branch Munitions Division, Chemical Systems Laboratory, Aberdeen Proving Ground, Jan. 1979, Open Literature Review.

7) Kolmer, Joseph R. "Rocky Mountain Arsenal, Basin A, Groundwater Quality Analysis", U.S. Army Engineer Waterways Experiment Station and Rocky Mountain Arsenal, July 1979 (Draft).

8) Rendon, Oswald, Herrero Consulting Engineer, "Alternatives for Containment of Polluted Groundwater Basin A Vicinity, Rocky Mountain Arsenal, Denver Colorado", Dec. 1977.

9) Records Research Team, Office of the DA Project Manager for Chemical Demilitarization and Installation Restoration, Installation Assessment of Rocky Mountain Arsenal, Records Evaluation Report No. 107, Vol. 1, March 1977 (Official Use Only).

10) Robson, S.G., "Digital-Model Study of Groundwater Contamination by Diisopropylmethylphosphonate (DIMP), Rocky Mountain Arsenal near Denver, Colorado", U.S. Department of the Interior, Geological Survey, June 1977 (Administrative Report For Official Use Only).

11) Timofeeff, Dr. Nicolay P., "Comprehensive Survey Plan for Soil and Groundwater Contamination at Rocky Mountain Arsenal, Colorado", Sept. 1976.

12) U.S. Army Medical Bioengineering Research and Development Laboratory, "Problem Definition Study on Land Pollution Limits at Rocky Mountain Arsenal", April 1975.

APPENDIX B

REFERENCE ARTICLES AND ABSTRACTS

APPENDIX B

1. Styron, C.R. III, U.S. Army Engineer WES, "Erosion Control At the ARES Facility, Kirtland Air Force Base, New Mexico", June 1972.

This report describes the application of a dust-control system consisting of DCA-1295 reinforced with fiberglass. The DCA is a polyvinyl acetate (PVA) that has been successfuly used to control soil erosion due to wind and rain.

2. Gabriels, D. and DeBoodt, M., 'Evaluation of Soil Conditioners for Water Erosion Control and Sand Stabilization' "Modification of Soil Structure," W.W. Emerson, R.D. Bond, and A.R. Dexter, eds., Wiley-Interscience, 1978.

Polyvinyl alcohol and poly acrylamide solutions, and bitumen and latex emulsions sprayed on a soil or sand surface were effective in reducing erosion in laboratory experiments with silt loam aggregates and in field trials on a loamy sand soil.

3. Amimoto, P.Y., "Erosion and Sediment Control Handbook", Department of Conservation, CA, EPA 440/3-78-003, May 1978.

This handbook discusses the procedures by which physical and climatic data and erosion control practices can be integrated to produce an erosion control plan. Most of the control practices involve structural measures, but there is some discussion of surface protection with mulches and other materials (plastic sheets, gravel and stone, etc.).

4. Ingles, O.G. and Metcalf, J.B., "Soil Stabilization, Principles and Practice", John Wiley & Sons, 1973.

This book discusses soil stabilization with respect to its engineering properties. The chapters on cement, lime, and bituminous stabilization, as well as the chapter or special methods of stabilization, and the one on methods and machinery for materials placement, do contain information pertinent to possible erosion control uses.

5. Brandt, G.H., "Soil Physical Property Modifiers", Dow Chemical Co., Marce Dekker Inc.

This book chapter mentions the various organic chemicals that have been used to modify soils to improve soil strength, aggregate stability, and water infiltration and to limit water adsorption, soil erosion, evaporation of moisture, and water seepage. The erosion control agents used for wind erosion control are enumerated and include such chemicals as residual oil, cutback asphalt, asphalt emulsions, polymerized styrene/butadiene latex emulsion, latex/oil mixture, copolymeric plastic dispersion, modified vinyl polymer, etc.

6. Franks, A.L. and White, C.A., "Demonstration of Erosion and Sediment Control Technology, Lake Tahoe Region of California," Calfornia State Water Resources Control Board, EPA-600/2-78-028, Dec. 1978.

This document discusses ways to reduce erosion impacts on streams and lakes by the use of careful planning and effective sediment/erosion control measures. All the measures involve the application of mulches as temporary protection prior to vegetative cover growth.

7. Sultan, Hassan A., "Soil Erosion and Dust Control on Arizona Highways", Part 1 State of the Art Review, ADOT-RS-10-141-I, Part 2 Laboratory Testing Program, ADOT-RS-10-141-II, Part 3 Progress Report - Field Testing Program, ADOT-RS-10-141-III, Part 4 Final Report - Field Testing Program, ADOT-RS-10-141-IV, Arizona Transportation and Traffic Institute, Nov. 1974.

Part I:

This report represents a comprehensive literature survey illustrating the past state-of-the-art concerning soil erosion due to wind, rain, and traffic forces. The emphasis throughout is on chemical stabilizers; for wind erosion these include calcium chloride, barium chloride, copper sulfate, barium sulfate, aluminum sulfate, sodium silicate, bitumens, lignin liquor, numerous resins and various polymeric materials.

Part II:

Forty-six commercially available chemicals were tested. These were tested under varying wind conditions and other durability and environmental conditions. Eleven chemicals were selected for field testing: Aerospray 70, Petroset 5B, Terrakrete #2, Formaine 99-194, Dresinate DS-60W-80F, Dust Control OIl, Surfaseal, Paracol 1461, Dust Stop, Coherex, Norlig 41 + FR5.

Part III:

This progress report gives the methodology of the chemical applications.

Part IV:

Six of the eleven chemicals were successful in achieving good dust control. Costs ranged between 4.3 and 10.9 cents per square yard. The six were: Terrakrete #2, Surfaseal, Dust Control Oil, Aerospray 70, Norlig 41 + F125, and Paracol 1461. All can be applied easily in the field using a small mobile sprayer. All were still providing effective control after 15 months.

8. West, J.R. ed., "New Uses of Sulfur", American Chemical Society, 1975.

A series of papers presented at a 1974 Symposium includes one on sulfur in coatings and structural materials. Investigations were made into the use of sulfur by itself and in combination with various unsaturated hydrocarbons, such as dicyclopentadiene, dipentene, styrene, CTLA polymer, and methylcyclopentadiene dimer. The most suitable sulfur modification was achieved with 6-7% dicyclopentadiene and 1% dipentene at 160°C.

9. Kays, W.B., "Construction of Linings For Reservoirs, Tanks, and Pollution Control Facilities," John Wiley & Sons, 1977.

This book describes the technology of linings for seepage control in hyrdraulic facilities used for water conservation and pollution control. The primary emphasis is on flexible lining materials i.e. plastic and elastomeric membranes and their basic manufacture, properties, testing, fabrication, cost, and installation techniques. Non-continuous lining systems such as cement concrete, gunite, asphalt concrete, compacted earth, bentonite, and chemical treatments are also examined.

10. Jones, L.W., Lutton, R.J. and Regan, G.L., "Design and Construction of Covers for Solid Waste Landfills," U.S. Army W.E.S., EPA-600/ 2-79-165 (PB 80-100381), Aug 1979.

This manual describes and evaluates various cover materials and presents design procedures relative to specific functional requirements and to controlling physical phenomenon. Natural soils as cover are the main subject; however, synthetic membranes, chemicals, and waste products are also discussed in detail.

11. Stewart, W.S., "State-of-the-Art Study of Land Impoundment Techniques," Exxon Research and Engineering Company, EPA-6001 2-78-196 (PB-291 881), Dec. 1978.

This report describes the results of a study of various liner materials used in land impoundment sites to contain seven general types of industrial waste. The objectives were to assemble information on the chemical and physical properties, cost, and field performance of various liners. Also, the compatibility of liners with specific industrial wastes was evaluated. The following list of materials was evaluated for liner potential:

1. Flexible membrane liners and fabric-reinforced (nylon, dacron, glass fiber) flexible membrane liners:

   a. Polyvinyl chloride (PVC)
   b. Polyethylene (PE)
   c. Polypropylene
   d. Butyl Rubber
   e. Chlorinated polyethylene (CPE)
   f. Ethylene propylene rubber (EPOM)
   g. Chlorosulfonated poly ethylene (Hypalon)
   h. Neoprene

2. Admixed materials:

   a. Asphalt concrete
   b. Soil cement
   c. Soil asphalt
   d. Sprayed asphalt membranes

3. Soil sealants:
   a. Rubber latex
   b. Bituminous sealcoat

4. Natural soil systems:

    a. Soil bentonite
    b. Compacted clays

The seven general industrial waste classifications were:

1. Caustic petroleum sludge
2. Acidic steel-pickling waste
3. Heavy-metal-bearing electroplating sludge
4. Toxic pesticide-formulation waste
5. Oily refinery sludge
6. Toxic pharmaceutical waste
7. Wastes from rubber and plastics industries

Oil resistant PVC, poly ethylene, polypropylene, soil cement, soil bentonite, and compacted clays are rated "good" for waste 4. The others are rated "fair".

12. Mura, R. and Thornburry, T.H., "Stabilization of Soils With Inorganic Salts and Bases - A Review of the Literature," Soil Machanics Laboratory, University of Illinois, Dec. 1969.

This report consists of an annotated bibiliography of the important literature on soil and aggregate stabilization with inorganic salts and bases published prior to 1965. Major attention is focused on stabilization with sodium chloride, calcium chloride, and sodium hydroxide. However, the main thrust is highway construction uses with little discussion of wind erosion control or infiltration.

13. Morrison, W.R., "Chemical Stabilization of Soils. Laboratory and Field Evaluation of Several Petrochemical Liquids For Soil Stabilization," Bureau of Reclamation, REC-ERC-71-30 (PB-205 800), June 1971.

This report summarizes laboratory tests conducted to evaluate the stabilization of unstable or erodible soils with various petrochemicals. These include:

Water-Base Stabilizers
1. Liquid vinyl polymer
2. Water soluble acrylic copolymer
3. Elastomeric emulsion
4. Epoxized-silicone material

Solvent-Base Stabilizers

1. Five liquid asphalt prime materials
2. Two petroleum resins

The vinyl polymer apparently did the best job of increasing bearing strength, resistance to wind and water erosion, and resistance to weathering.

14. Morrison, W.R. and Simmons, L.R., "Chemical and Vegetative Stabilization of Soils. Laboratory and Field Investigations of New Materials and Methods for Soil Stablization and Erosion Control," Bureau of Reclamation, REC-ERC-76-13 (PB0268 458), Jan 1977.

This report summarizes three main work items conducted under two major programs. The items are: 1) Laboratory Studies, 2) Field Applications, and 3) State-of-the-Art Survey. Laboratory Studies - Thirty liquid soil stabilizing products underwent screening tests on soils. The tests were for: 1) compressive strength, 2) water erosion, 3) penetration, 4) wind erosion, and 5) weathering. The thirty chemicals included a variety of latex, poly vinyl acetate, alkyd, resin, asphalt, elastomeric, and copolymer emulsions as well as urethane and liquid silicon compounds.

Field Applications - These include the use of a hard-base asphalt cutback on dune sand, of a poly vinyl acetate on backfill material, of a urethane soil binder on a gravel lining, of lime to stabilize clay canal banks, and of chemical and vegetative erosion control methods.

State-of-the-Art Survey - Literature searches were conducted on 1) chemical soils stabilization, and 2) revegetation methods and materials for erosion control.

Results and Conclusions - Of the 24 water-based materials tested for their ability to meet the performance requirements (compressive strength, resistance to water erosion, weatherability) seven met all the requirements. These included five poly vinyl acetate emulsions and two vinyl acrylic copolymer emulsions.

15. Ferm, R.L. "Asphalt Emulsions," Chevron Research Co., M. Dekker Inc., 1974.

This chapter summarizes background information and recent developments in asphalt emulsion use. Section XI briefly discusses the use of asphalt emulsions in soil-erosion control, in particular wind erosion.

✓16. Wyant, D.C., et al., "Erosion Prevention During Highway Construction By the Use of Sprayed On Chemicals," Virginia Highway Research Council, VHRC 72-R1 (PB-213-207), July 1972.

Nine commercial spray on plastic chemicals were evaluated as erosion inhibitors. All were compared with straw tacked with asphalt emulsion and with untreated soil. Chemical costs and economic feasibility were also determined. A number of different soil and slope combinations were tested with the chemicals. No chemical performed better or cost less than the straw/emulsion, but some did show significant erosion protection. The following chemicals were tested: Aerospray 52 (alkyd emulsion resin), Aerospray 70 (poly vinyl acetate emulsion resin), Curasol AE (polymer synthetic resin dispersion), DOW NC-1556.2L (discontinued), Norlig 41 (discontinued-contained resins, sugars and lignosulphonic acids), Soil Gard (inert polymer elastomeric emulsion), Terra Tack (vegetable powder), Erode-X (mulch), and Petroset SB (rubberized emulsion).

17. Wilder, C.R., "Soil Cement for Water Resource Structures", Transactions of the ASAE, 1977.

This paper discusses the uses of soil cement as slope protection for earth dams and embankments and impervious lining for reservoirs and lagoons.

18. Dhawan, B.L. and Rastogi, M.C., "Stabilization of Sandy Soils by Chemical Additives: Part I - Adsorption of Surface Active Agents at Soil/Water Interface," Indian Journal of Chemistry, Vol 12, Feb 1974.

This paper discusses the chemical adsorption characteristics of dodecylpyridinium chloride in soils. This chemical is used to improve the compaction properties of soil.

√ 19. Lyles, L., Schmeidler, N.F. and Schrandt, R.L., "Commerical Soil Stabilizers for Temporary and Wind-Erosion Control," Transactions of the ASAE, 1974.

This paper discusses the evaluation of thirteen commerical soil stabilizers in laboratory wind-tunnel and raintower tests. Effective stabilizers were then tried in field tests and were able to minimize erosion for up to six weeks. They were not evaluated for longer periods.

20. Hurley, C.H. and Thornburn, T.H., "Sodium Silicate Stabilization of Soils: A Review of the Literature", Highway Research Rec, 1972.

The report consists of an annotated bibliography and summary review of the main literature on the use of sodium silicates in soil stabilization processes. It contains a summary of pertinent information on stabilizer properties, reaction mechanisms, injection methods of soil solidification, properties of stabilizer-soil mixtures, and use of sodium silicates as dust proofers and waterproofers and as secondary additives with other stabilizers. Sodium silicates with or without the addition of precipitants are of little value in dustproofing or waterproofing fine-grained soils but may have some application to coarser grained sands.

21. Kay, B.L., "Mulches for Erosion Control and Plant Establishments on Disturbed Sites," University of California, in Agronomy Progress Report, No. 87, May 1978.

Commonly used mulches are organic fibers (straw, hay, wood-cellulose fibers applied by hydromulching, wood residues as wood chips and bark), fabric or mats, soil, and rock. Proper use of each mulch is discussed, including rate and method of application and limitations.

22. Cross, J.M., "Need for a New Approach Stressed at Great Plains Windbreak Symposium," Soil Conservation, June 1976.

This article discusses the results and conclusions of the April 20-22, 1976 Windbreak Symposium in Denver, Colorado. Maintaining and improving tree windbreaks is recommended.

23. Harem, F.E., Bielman, K.D., and Worth, J.E., "Reservior Linings," Journal AWWA, May 1976.

This article describes some of the applications of asphalt concrete and plastic linings for reservoirs in the potable water industry. Lining types considered are the following: hydraulic asphalt concrete (HAC), prefabricated asphalt panels (PAP), synthetic rubber, butyl rubber (BR), chloroprene rubber (neoprene), chlorsulfonated polyethylene (Hypalon-DuPont), polyvinyl chloride (PVC), ethylene propylene diene monomer (EPDM), and chlorinated polyethylene (CPE).

24. Noble, E.R., "Elastomeric Membranes", Water Services, August 1977.

This brief article discusses the use of elastomeric membranes in the water industry. Butyl, EPDM, chlorosulphonated polyethylene, and nitrile PVC are examined for their suitability.

25. Baker, J.W., "Polypropylene Fiber Mat and Asphalt Used for Oxidation Pond Liner", Water and Wastes Engineers, November 1970.

A refinery in Alaska had a strong flexible waterproof lining (asphalt-coated polypropylene fiber mat) installed in their oxidation pond.

26. Römkens, M.J.M., Johnson, C.B., and Nelson, D.W., "Soil Erosion Control on Construction Sites with Portland Cement".

This article reports on a study to determine suitable rates and methods of cement application for erosion control on construction sites. The erosion is caused by rainfall and doesn't include wind effects.

27. Kays, W.B., "Clearing Up Some Misconceptions about Basic Lining Technology", Water and Sewage Works, October 1977.

This brief article discusses lining materials classified as continuous, flexible, impervious membranes and gives some general rules to follow in lining selection.

28. Kumar, J., and Jedlicka, J.A., "Selecting and Installing Synthetic Pond-Linings", Chemical Engineering, February 5, 1973.

This short article describes the properties of commonly used lining materials (polyethylene, polyvinyl chloride, chlorinated polyethylene, polypropylene, nylon, butyl rubber, natural rubber, hypalon) and how to select and install the appropriate liner.

29. Hsieh, J.J.C., and Wildung, R.E., "Bentonite Stabilization of Soil to Resist Wind Eronsion", Soil Sci. Soc. Amer. Proc.,Vol. 33, 1969.

Preliminary investigations indicate that the addition of bentionite to soil followed by moistening will significantly reduce the susceptibility of the soil to wind erosion after drying.

30. Vomocil, J.A., and Ramig, R.E., "Wind Erosion Control on Irrigated Columbia Basin Land, A Handbook of Practices," Oregon State University Extension Service, October 1976.

A series of general recommendations for soil management practices are given. These are oriented to agricultural erosion control.

31. "Potential Use of Asphalt Emulsion in Solid Waste Disposal," Battelle Northwest Prospectus, 1979.

This describes a proposed project to investigate the use of asphalt emulsion sealants to control leachate from coal sludges or residues.

32. Sultan, H.A., "Chemical Stabilization for Control of Dust and Traffic Erosion," University of Arizona, 1976.

Forty-six commercially available chemicals were tested. Based on laboratory test results several chemical stabilizers were chosen for large-scale field application. The material in this report is essentially the same as that in the 4 volume Arizona DOT report (ADOT-RS-10-141-11). The top five chemicals in performance for dust control were:

1. Terrakrete #2
2. Surfaseal 1:10
3. Dust control oil, 1.13 liter/m^2 (1/4 gal/yd^2)

4. Norlig 41 + F125
5. Coherex

These are preliminary results. Application costs were less then 10.8 cents/m^2 (9 cents/yd^2).

33. Kawamura, M., and Diamond, S., "Stabilization of Clay Soils Against Erosion Loss," Clays and Clay Minerals, Vol. 23, 1975.

Soil erosion from construction sites may be decreased by incorporation of small amounts of soil stabilizers such as calcium hydroxide or Portland cement. Soil detachment by raindrop impact was investigated.

34. Swan, J.B., Halsey, C.F., Breyer, D., "Wind Erosion: Its Control in Minnesota", Agricultural Extension Service.

This folder and an accompanying fact sheet describe agricultural methods of soil erosion control.

35. Blavia, F.J., Moldenhauer, W.C., and Law, D.E., "Materials for Stabilizing Surface Clods of Cropped Soils", Soil Sci. Soc. of Amer. Proc. Vol. 35, 1971.

Thirteen chemicals were sprayed on clods to increase soil resistance to erosion by rainfall.

36. Gabriels, D.M., Moldenhauer, W.C., and Kirkham, D., "Infiltration, Hydraulic Conductivity, and Resistance to Water-Drop Impact of Clod Beds as Affected by Chemical Treatment", Soil Sci. Amer. Proc., Vol. 37, 1973.

Polyvinyl alcohol (PVA) and bitumen emulsions were tested.

37. Armbrust, D.V., A Review of Mulches to Control Wind Erosion", Transactions ASAE, 1977.

Crop residues and a variety of chemical soil stabilizers can provide short-term or temporary wind erosion control.

38. Sommerfeldt, T.G., "Soil-Asphalt Mixture for Canal Seepage Control: Laboratory Study," Canadian Agricultural Engineers, Vol. 19, Dec. 1977.

A material for lining irrigation canals composed of soil, anionic asphalt emulsion, Wyoming bentonite, an enzymatic wetting agent, and water was developed.

39. Rostler, F.S., Emulsions and Their Use in Soil Treatment, Patent 3,592,788, July 13, 1971.

Two emulsion concentrates comprising a stryene-butadiene block copolymer, a coumarone-indene resin, a solvent of the aromatic hydrocarbon type, and polar solvents are claimed to be able to resist even severe and unusual winds, rains, and surface waters when applied to various soil types.

40. Nimerick, K.H., Method of Preventing Environmental Erosion, Patent 4,087,572, May 2, 1978.

A surface coating agent consisting of an orgnaic polymer latex and a silicone is applied in two steps to masses of particulate matter to prevent wind and rain erosion.

41. Jankowiak, E.M., Brandt, G.H., Straw Mats for Soil Erosion Control, Patent 3,867,250, February 18, 1975.

Straw mats composed of straw bound with a water resistant adhesive are used to control wind and rain erosion in agriculture and construction activities.

42. Kupiec, A.R., Escher, E.D., Method of Converting Hazardous Industrial and Other Wastes Into an Inert, Non-Polluting and Useful Soil-Like Product, Patent 4,149,968, April 17, 1979.

Bentonite clays and Portland cements are mixed with aqueous solutions of wastes to produce solid masses.

43. Adams, N.M., Composition and Method of Agglomerating and Stabilizing Particulate Matter by Chemical Treatment, Patent 3,371,712, Mar. 5, 1968.

This relates to a method of chemical treatment of particulate matter to produce cohesive masses capable of withstanding continuous pressures and environmental forces.

44. Fisher, S.G., Soluble Fibrous Material for Controlling Soil Erosion, Patent 3,315,408, April 25, 1967.

A biodegradable protective covering is designed to minimize soil erosion prior to vegetative germination.

45. James, T.H., Soil Penetrating, Compacting and Cementing Composition, Patent 3,943,078, March 9. 1976.

Aqueous mixtures containing a synthetic latex material etc. are designed to improve the compaction characteristics of soils.

46. Dawes, J.W., Seligman, K.L., and Smith, S.G., Heat-Sealable Composition, Patent 1,466,190, March 2, 1977.

A polymer composition is designed to be formed into thin sheets and firmly sealed together with heat. The sheets are used to line pits, ponds, and lagoons.

47. Peck, R.F., and Simpson, A.J., Soil Consolidation Process, Patent 1,373,020, November 6, 1974.

This process concerns the consolidation of sandy soils by treatment with aqueous poly butene emulsions. These soil stabilizers are used in agricultural applications to control wind erosion.

48. Cornay, C.J., and Ryffel, J.R., A Method for Lining Ponds, Pits, Dams, Wells, and Canals, Patent 1,139,258, January 8, 1969.

This concerns the use of flexible sheets of chlorianted polymers of ethylene as lining materials. Production methods are described.

49. Grafmuller, F., Method for the Consolidation of Soil, South Africa Patent 69/6038, August 31, 1969.

This relates to soil consolidation to control erosion of agricultural soil with applications of synthetic polymeric dispersions.

APPENDIX C

REFERENCE BOOKS

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1. Building Construction Cost Data 1978, 36th Annual Edition, Robert Snow Means Company, Inc., Duxbury, Massachusetts.

2. Cherry, J.A., and Freeze, R.A., Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

3. Handbook of Heavy Construction, Second Edition, Edited by J.A. Havers and F.W. Stubbs, Jr., McGraw-Hill Book Company.

4. Linsley, R.K. Jr., Kohler, M.A., Paulhus, J.L.H., Hydrology for Engineers, Second Edition, McGraw-Hill Book Company.

5. Sowers, G.B., and Sowers, G.F., Introductory Soil Mechanics and Foundations, Third Edition, MacMillan Publishing Company, Inc.

APPENDIX D

CONSTRUCTION COST DATA

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CONSTRUCTION COST DATA

Data relevant to developing cost information on the placement of materials, compaction of materials, earth hauling, grading, placing concrete and construction crews is presented in this Appendix. The data, as presented, was extracted and interpreted from the book Means Building Construction Cost Data 1978.

Material Placement, borrow, buy and load at pit, haul 2 miles to site, place and spread, with 180 H.P. dozer, no compaction. Prices quoted here exclude the estimated material costs. For all materials except concrete, the installation cost is $1.40/ cubic yard (C.Y.)(1978). An estimated cost for 1980 is $1.65/C.Y., assuming about a 9 percent annual inflation rate. Use proper number of B-15 crews, each with a daily output of 600 C.Y.

Compaction, of common fill using sheepsfoot or wobbly wheel roller, 8" lifts. This would only be needed for soil layers. Equipment cost is $0.54/C.Y. and labor cost is $0.39/C.Y., for a total cost in 1978 of $0.93/C.Y. An estimated cost for 1980 is $1.10/C.Y., assuming about a 9 percent annual inflation rate. Use proper number of B-10G crews, each with a daily output of 360 C.Y.

Hauling Earth, 20 C.Y. dump trailer. A 1 mile round trip at 2.6 loads/hr cost $0.43/C.Y. for equipment and $0.20 for labor, for a 1978 total of $0.63/C.Y. An estimated cost for 1980 is $0.75/C.Y. assuming about a 9 percent annual inflation rate.

A 4 mile round trip at 1.5 loads/hr cost $0.72/C.Y. for equipment and $0.34 for labor, for a 1978 total of $1.06/C.Y. An estimated cost for 1980 is $1.26/C.Y., assuming about a 9 percent annual inflation rate. Use proper number of B-34D crews, each with a daily output of 400 C.Y. for a 1 mile round trip and of 240 C.Y. for a 4 mile round trip.

Grading, Site excavation and fill, not including mobilization, demobilization or compaction. Includes 1/4 push dozer per scraper.

Dozer, 300 ft. haul, 270 H.P. $\approx$ 70 C.Y./hr. Equipment cost is $0.78/C.Y. and labor cost is $0.25/C.Y.; total cost for 1978 is $1.03/C.Y. An estimated cost for 1980 is $1.22/C.Y., assuming a 9 percent annual inflation rate.

Self-propelled scraper, 25 C.Y. 1000 ft haul $\approx$ 200 C.Y./hr. Equipment cost is $0.87/C.Y. and labor cost is $0.22/C.Y.; total cost for 1978 is $1.09/C.Y. An estimated cost for 1980 is $1.30/C.Y., assuming a 9 percent annual inflation rate.

Use appropriate number of B-10M crews, each with a daily output of 560 C.Y., for the dozer. Use appropriate number of B-33E crews, each with a daily output of 760 C.Y., for the scraper.

Concrete In Place, Ground slab including troweled finish, not including forms or reinforcing over 10,000 S.F.

4" thick slab. Material cost is $0.37/S.F. and installation cost is $0.38/S.F.; total cost for 1978 is $0.75/S.F. An estimated cost for 1980 is $0.44/S.F. for material and $0.45 for installation, assuming a 9 percent annual inflation rate. However, based on a vendor's quote of $45.00/C.Y. for concrete, the actual 1980 material cost is about $0.56/S.F. This number will be used on conjunction with the $0.45 for installation.

Use appropriate number of C-8 crews each with a daily output of 2025 S.F.

Construction Crew Data

B-10 Crew

1 Equipment Operator
.5 Building Laborer
Add equipment below

B-10G

1 Sheepsfoot Roller, 130 H.P.

B-10M

1 Dozer, 270 H.P.

B-15 Crew

B-10 Crew
2 Truck Drivers
2 Heavy Trucks
1 Dozer, 180 H.P.

B-33E Crew

B-10 Crew
.25 Equipment Operator
1 Self-Propelled Scraper, 25 C.Y.
.25 Dozer, 270 H.P.

B-34D Crew

1 Truck Driver
1 Truck Tractor, 40 Ton
1 Dump Trailer, 20 C.Y.

C-8 Crew

1 Labor Foreman
3 Building Laborers
2 Cement Finishers
1 Equipment Operator
1 Concrete Pump

Battelle
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Telephone (614) 424-6424
Telex 24-5454

August 14, 1980

Mr. Allan McKinney
U.S. Army Toxic and Hazardous
Materials Agency
Aberdeen Proving Ground, Maryland 21010

Attention: DRXTH-IS

Dear Allan:

Attached is the "Basin A Study" final report prepared as part of Delivery Order 1523. Changes to the report resulting from your letter dated July 30, 1980 have been incorporated.

It has been a pleasure working with you on this study.

Sincerely,

David E. Johe
Research Scientist
Energy and Enivronmental
Systems Assessment Section

DEJ/ps

Attachment: Recommendations

RECOMMENDATIONS

BCL recommends that USATHAMA review both long-term techniques, and select one in light of the long-range plans for RMA. If the bentonite cover technique is acceptable based on that review, it should be implemented as soon as is practical to avoid the necessity of implementing short-term control measures. This would eliminate the additional expense of covering the basin with a layer of local uncontaminated soil prior to placing the bentonite clay.

When implementing any of the techniques described herein, disturb the in-place basin soil as little as possible. This will minimize the exposure of the workers to toxic and hazardous contaminants.

If the local soil bentonite clay cover is utilized, it will be necessary to prevent deep-rooted vegetation from becoming established. It will also be necessary to prevent prairie dogs from burrowing through the bentonite clay barrier.

If the concrete cover is utilized, perform annual maintenance to remove vegetation from cracks and joints, and seal all cracks and joints.

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ABILIZATION...

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Rocky Mountain Arsenal
Information Center
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